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HYDRODYNAMIC AND AERODYNAMIC TESTS OF MODELS OF
FLYING-BOAT HULLS DESIGNED FOR LOW AERODYNAMIC DRAG

N.A.C.A. MODELS 74, 74-A, AND 75

By Starr Truscott, J. B. Parkinson,
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SUMMARY

N.A.C.A. models 74, 74-A, and 75 were tested in the N.A.C.A. tank to determine their hydrodynamic properties and in the N.A.C.A. 20-foot wind tunnel to determine their aerodynamic properties. The forms of these models were derived from that of a solid of revolution having a low air drag, and the departures from the form of this low-drag body were the minimum considered to give satisfactory take-off performance. Model 74 has a rounded bottom with flared chines, a transverse step with a small fairing aft of it, and a pointed afterbody. Model 74-A has the same form except for the removal of the fairing aft of the step. Model 75 has a pointed step and a horizontal afterbody derived from the form of the N.A.C.A. model 35 series.

The models were tested in the tank free-to-trim and at fixed trim according to the general method. The general test data from the tank are presented in the form of resistance and trimming-moment coefficients against trim. The wind-tunnel results are given as drag coefficient against trim. The take-off performances of models 74-A and 75 are compared by take-off calculations for a hypothetical seaplane having 250,000 pounds gross weight.

When compared on the basis of equal volumes, each of the models has a lower aerodynamic drag than any model of a conventional hull tested in the 20-foot wind tunnel. Model 74-A has lower drag than model 75 but model 75 has lower resistance at high speeds on the water and better take-off performance for the hypothetical seaplane investigated. The aerodynamic refinement leads to high water resistance at certain combinations of trim and load, but satisfactory take-off performance can be attained by proper control of the trim.

INTRODUCTION

The aerodynamic drag of conventional flying-boat hulls is from 75 to 150 percent greater than that of an airship form having the same frontal area (reference 1). This high drag is relatively unimportant where, as has commonly been the case, it is a small part of the total drag of the seaplane, but, with the high wing loadings associated with very large flying boats, it may easily be as much as 25 percent of the total drag. For such aircraft, a sizeable reduction in hull drag will have a large favorable effect on the flight performance.

Unfortunately, the form of the hull is influenced by considerations which conflict with that of low aerodynamic drag. Any reduction in drag obtained simply by reducing the size of the hull is limited by the smallest size necessary for adequate seaworthiness, suitable take-off performance, and space for accommodation of the useful load. Reduction in drag by aerodynamic refinement of the form can be carried only to the extent beyond which the allowable water performance is impaired. The limitations of the size are determined by the intended service and thrust available; those of the form must be found by experiment.

A general program having for its purpose the development of low-drag forms of hulls suitable for high-performance flying boats and the provision of systematic design data regarding such forms is being undertaken by the Committee. As an exploratory step to determine the possible value and scope of this program, two models with what were considered the minimum of departures from a streamline body commensurate with satisfactory water performance have been tested in the N.A.C.A. tank and in the N.A.C.A. 20-foot wind tunnel. The data from the tests are reported at this time as an aid in design studies for flying boats in which the drag of the hull is an important consideration.

DESCRIPTION OF MODELS

A survey of the forms of successful flying-boat hulls indicates that the best shape of the basic streamline form from which a low-drag hull may be derived will differ from that of an airship in the following particulars: The basic form should have a more forward position of the maximum

ordinate and a greater fineness ratio than the airship form in order that the planing surfaces and the tail extension can be properly proportioned. The basic form should have more volume forward for seaworthiness and a finer form aft to minimize interference with spray. The after end of the basic form must be raised to provide satisfactory clearance of the tail extension on the water and an elevated support for the tail surfaces.

The forms of N.A.C.A. models 74 and 75 were therefore based on an arbitrary solid of revolution with a fineness ratio of 7.22, the maximum ordinate at 30 percent of the length, and the prismatic coefficient 0.606. The axis of revolution was curved upward aft to give the minimum clearance of the tail thought to be necessary. The longitudinal distribution of the volume of this basic form is compared in figure 1 with that of a typical low-drag fuselage form, N.A.C.A. form 211 (reference 2), and of two typical airship forms.

The lines of the models are shown in figures 2 and 3, and the corresponding offsets are given in tables I and II. Model 74 has a rounded bottom closely following the shape of the basic form, a shallow transverse step, and a pointed afterbody. This form has a fairing aft of the step shown in figure 2. After preliminary tank tests, the fairing was removed in an attempt to improve the water characteristics, and the altered model was designated model 74-A.

Model 75 has a form derived from N.A.C.A. model 35 (reference 3), the characteristic pointed step and great afterbody clearance of this form being used to obtain low resistance at high planing speeds. The bow is like that of model 74-A, but the rounded bottom forward gradually changes to a V-bottom and keel near the step. Unlike the form of model 35, the afterbody chine fades out at a point nearly above the step and the height of the vertical side above the forebody chine is reduced to almost zero.

The trim, in the hydrodynamic data, and the angle of pitch, in the aerodynamic data, are the angle between the model base lines and the horizontal.

Photographs of the models showing details of the forms of the bottoms are given in figures 4 and 5. The models are made of laminated mahogany and were carefully finished with several coats of pigmented varnish.

In the derivation of the hull lines, the departures from the basic form were kept as small as were thought possible for satisfactory water performance. The plan forms of the models were held the same as that of the basic form, and other changes were made wholly outside and below the circular sections of the basic form. The lines are therefore useful for cases in which the interior is to be supercharged for passenger comfort at high altitudes, the basic form becoming the pressure cabin. In both models, the chines at the bow were located in diagonal planes through the axis of the basic form to minimize the flow across them at low angles of attack.

HYDRODYNAMIC TESTS

Apparatus and Procedure

The models were tested in the N.A.C.A. tank (reference 4) using the towing gear described in reference 5. The tests were made in October 1937, immediately after the towing carriage had been rebuilt for high-speed operation but before rather severe vibration caused by eccentricity of the wheels and tires had been eliminated. This vibration introduced some errors into the data taken above 25 feet per second because of the added difficulty in reading and recording mean values. These errors were reduced as much as possible in the fairing of the curves.

The models were first tested free-to-trim at one assumed value of gross load and get-away speed, the load on the water being adjusted by the hydrofoil lift device described in reference 4. In these tests, the models were pivoted about the centers of moment shown in figures 2 and 3 and were balanced vertically and horizontally about the pivot. General tests at fixed trim were then made over a range of speeds, loads, and trims intended to include all useful combinations of these variables.

The measured resistance includes the aerodynamic drag of the model. The values of trimming moment likewise include any aerodynamic moment of the model and the values of load include that carried by any aerodynamic lift of the model. These aerodynamic forces are considered to be negligible but are properly included when the test results are intended for design calculations.

Results and Discussion

The results of the tank tests are given in the form of the usual nondimensional coefficients defined as follows:

$$\text{Resistance coefficient, } C_R = R/wb^3$$

$$\text{Load coefficient, } C_\Delta = \Delta/wb^3$$

$$\text{Speed coefficient, } C_V = V/\sqrt{gb}$$

$$\text{Trimming-moment coefficient, } C_M = M/wb^4$$

where R is resistance, lb.

Δ , load, lb.

V , speed, f.p.s.

M , trimming moment, lb.-ft.

b , maximum beam, ft.

w , specific weight of water, lb./cu. ft.

g , acceleration of gravity, 32.2 ft./sec.²

Any other consistent system of units may be used to form these coefficients.

Free-to-trim.— The results of the free-to-trim tests for a typical condition of loading are plotted in figure 6. In this figure model 74-A has lower resistance at low speeds although it trims higher. The minimum Δ/R of model 74-A at the hump speed is about 4.7, and, if the sharp peak at the hump for model 75 can be considered as having little adverse effect on the take-off, the minimum Δ/R of model 75 is approximately the same. The trim of model 75 at high speeds is too low, and hence its resistance is much higher. It will be shown later, however, that the resistance at best trim of model 75 at these speeds is lower than that of model 74-A; hence the comparison at high speeds in this figure is of no importance if it is assumed that the trim for both models will be properly controlled.

Free-to-trim tests of model 74 were not made at the

initial load used with models 74-A and 75 but corresponding data deduced from the preliminary general tests of this model indicated that the fairing of the step shown in figure 2 had a negligible effect on the free-to-trim resistance up to a speed coefficient of 4.0.

Typical photographs of the models taken during the free-to-trim tests are given in figures 7 and 8. If anything, model 74-A ran cleaner than model 75 at low speeds but, as may be seen from the figures, the differences in the height and the volume of objectionable spray are small. The after ends of both models were wetted at low speeds and a lower position of the tail to obtain a further reduction in aerodynamic drag does not appear to be desirable. Model 75 has a higher roach aft of the tail than does model 74-A but the pictures indicate that tail surfaces located above the deck line and forward of the after perpendicular will be clear of spray from the afterbody in either case.

The low bow resulting from the close adherence to the streamline form is heavily wetted at very slow speeds. The objectionable flow around it rapidly disappears as the speed and the trim increase, and at hump speed its form should have a negligible effect on the spray formation except in extremely heavy seas. As a part of the general program, it is planned to obtain some qualitative information on the behavior of such forms of bow in short choppy waves.

General tests.— The most important use of general test data is considered to be in calculating the take-off performance of hulls derived from model lines for specific design problems. By this means, the relative merit of different hull forms may be determined and changes in size or in the aerodynamic characteristics of the seaplane may be evaluated in terms of time and distance of take-off or overload capacity. The general test data of models 74-A and 75 (figs. 9 and 10) are therefore presented in the form of resistance and trimming-moment coefficients against trim for selected speed coefficients. This form of plot has been found to be more directly applicable in performing the calculations than the usual plots against speed coefficients because the water resistance at a given speed is a function of the trim, which is in turn a function of the trimming moments acting.

The arrangement of the data in this form immediately

broadens the scope of the general test in determining the effect of parameters influencing the take-off performance. At low speeds where the water forces are predominant, the hull is usually assumed to be free-to-trim; that is, the hydrodynamic moment about the assumed center of gravity is zero and the sum of the aerodynamic moments is zero. For the centers of moment used in the tests, this condition is found where the curves of trimming-moment coefficient cross zero and is represented by the dotted lines crossing the curves of resistance coefficient in the figures. For other positions of the center of gravity, the trim is simply the value for which the trimming-moment coefficient referred to the center of moments is equal and opposite in sign to that of the weight with respect to the center of moments. Similarly, the effect of the large negative thrust moment existing in present-day flying boats or the effect of a control moment from the elevators can be determined. The effect of elevator force in changing the load on the water can be included, although the accuracy of the data applying to the full-size hull does not usually justify such precise computation.

At high speeds, where the aerodynamic forces predominate, the trim is usually determined by the aerodynamic moments and can be controlled at will by the pilot. For design purposes, the desirable procedure in this case is to assume that the pilot will use the trim at which the total resistance is a minimum in order to make the shortest take-off.

The minimum water resistance and the trim at which it occurs are indicated in figures 9 and 10 by the solid lines crossing the curves of resistance coefficient that have definite minimum points. The corresponding values of trimming-moment coefficient are found from the lower curves of the figures. These values at various load coefficients are plotted against speed coefficient in figures 11 to 14 and their use in take-off calculations is described in reference 6.

It has commonly been assumed that the trim for minimum water resistance is substantially the same as that for minimum total resistance; this assumption proved valid in the earlier cases investigated. With the high wing loadings and the high get-away speeds of large seaplanes, however, it is not necessarily true at the stalling speed and beyond; hence the data of figures 11 to 14 do not always apply for obtaining the shortest take-off. A more

satisfactory approach to the best take-off may be made by calculating the total resistance at several constant trims in the high-speed range and determining the best trim from the lower envelope of the family of curves thus obtained. At speeds greater than stalling speed, the best trim may become greater than that for minimum water resistance. The methods of calculation using the test data in figures 9 and 10 are described in more detail in the section on take-off performance.

The most favorable angle of wing setting compatible with the trim of the hull at cruising speeds may be found in a similar manner. The lowest total resistance at several wing settings is calculated and plotted against speed. The best setting is thereby found over the range of speeds from hump to get-away rather than at one arbitrary speed. For very high wing loadings, the best wing setting is usually higher than can be used for best flight performance and the actual setting will therefore be determined by the allowable trim in flight.

Sticking.— The tests showed that the performance of the models is unsatisfactory at certain combinations of trim, speed, and load that might be encountered in some applications of the lines. Model 74-A has a "worst trim" condition at light loads and speed coefficients above 4.5, in which the afterbody is approximately parallel to the free-water surface. The effect on resistance is shown in figure 9 at $C_v = 5.0$. At 5° trim, the curves for $C_\Delta = 0.05$ and 0.1 are normal, corresponding to the usual spray pattern around the afterbody. As the trim is increased, the flow suddenly covers the entire afterbody bottom, resulting in a vertical instability and the high resistance shown in the figures. Further increase in trim brings the forebody clear of the water and the resistance and general behavior become normal for a model running only on the afterbody. At $C_v = 5.5$, the same phenomenon occurs for the next heavier load coefficient at 8° trim. Similar tendencies persist at higher speed coefficients.

This abnormal behavior is attributed to the round cross sections forward and aft of the step and to insufficient depth of step, both features of the form being the result of extreme aerodynamic refinement. If the aerodynamic drag is to be kept as low as possible, the condition can readily be avoided by proper control of the trim. Generally speaking, the limit to the aerodynamic refinement

possible for a hull does not appear to be well defined, the actual extent depending on the requirements of the design.

Figure 10, $C_v = 5.0$ to 6.0 , shows some sticking of model 75 at 8° trim for load coefficients of 0.2 and 0.3 . In this case, the increase in resistance is caused by spray from the forebody running over the afterbody chine and up the side of the basic form; it is not likely to be met with in practice because of the high trim at which it occurs. The water performance of model 75 could be improved by increasing the width of the afterbody and carrying the afterbody chine farther forward but here again a compromise must be made with the requirement of low aerodynamic drag.

Typical spray photographs at high speeds (figs. 15 and 16) illustrate the adverse effect of the close adherence of the models to the form for low aerodynamic drag on the cleanness of running. In figure 15(a) the resistance and stability of model 74-A are satisfactory but there is considerable flow over the afterbody and the under side of the tail. Figure 15(b) at the same speed and load but at a higher trim shows the model running on the afterbody. Only the under side of the tail is wetted. A picture of the "worst trim" condition between these trims is not available but the effect on the spray pattern is similar to that shown in figure 15(c). As pointed out before, this condition may be avoided by holding the trim at high speeds to 5° or lower.

In figure 16(a), model 75 is running cleanly at 4° trim but, in figures 16(b) and 16(c), the spray runs up along the basic form because of the insufficient afterbody chine in the vicinity of the step. In this form also, the objectionable spray and the resistance may be kept within reasonable limits by proper control of the trim.

Take-off performance.— In order to compare the two hulls on the basis of take-off performance, a take-off calculation was made for a large hypothetical flying boat having the following characteristics:

Gross weight - - - - - 250,000 lb.

Wing area - - - - - 5,560 sq. ft.

Horsepower available for take-off - -	15,000
Wing loading - - - - -	45 lb./sq. ft.
Power loading at take-off - - - - -	16.7 lb./hp.
Span - - - - -	236 ft.
Mean chord - - - - -	23.6 ft.
Geometric aspect ratio - - - - -	10
Angle of wing setting - - - - -	7°
Split flaps - - - - -	0.20 chord 0.60 span
Flap deflection assumed during take-off - - - - -	30°

The take-off is on smooth water with no wind at standard sea-level conditions.

The high-speed resistance for both models was also determined for an angle of wing setting of 5° but was higher than that with the wing set at 7°. It was inadvisable to use an angle higher than 7° because, in flight, the hull would then be at some trim lower than that of minimum air drag.

Lift and drag curves were estimated from unpublished wind-tunnel data. They are shown in figure 17 with the flaps down 30°.

It was assumed that the flying boat trimmed freely, taking into account the effect of the thrust of the propellers, until 55 percent of the get-away speed was reached, at which point the pilot took command and held the trim at that of least total resistance up to a speed just below get-away. The get-away was effected by a slight pull-up to 5° to take off at 147.5 feet per second or 15 percent above the stalling speed.

The hull size was assumed to be such that the gross load coefficient at rest, C_{Δ_R} , was 0.55. This size gave a beam of 19.2 feet and the following constants:

$$C_{\Delta} = \frac{\Delta}{64(19.2)^3} = \frac{\Delta}{455000} \quad (1)$$

$$C_R = \frac{R}{64(19.2)^3} = \frac{R}{455000} \quad (2)$$

$$C_V = \frac{V}{\sqrt{32.2 \times 19.2}} = \frac{V}{24.9} \quad (3)$$

$$C_M = \frac{M}{64(19.2)^4} = \frac{M}{8730000} \quad (4)$$

The lift and the drag of the wing were computed as follows:

$$L = 1/2 \times 0.002378 \times 5560 C_L V^2 = 6.60 C_L V^2 \quad (5)$$

$$D = 1/2 \times 0.002378 \times 5560 C_D V^2 = 6.60 C_D V^2 \quad (6)$$

The thrust curve was assumed to be that produced by ten 1,500-horsepower engines with 14-foot constant-speed propellers. The power plant of so large a flying boat probably would have a smaller number of more powerful units but, in the light of existing data, it was impractical to extrapolate any farther. The thrust of the propellers was assumed to act 8 feet above the center of gravity. Since the thrust acts to depress the bow of the boat, the thrust moments are negative. In the free-to-trim phase of the take-off, the water moments must be equal and opposite to the thrust moments for equilibrium. An example of the calculation using this method of considering the thrust moment follows:

<u>Symbol</u>	<u>Definition</u>	<u>Where derived</u>	<u>Value</u>
C_{Δ_R}	Load coefficient at rest		0.55
V_G	Assumed get-away speed, f.p.s.		147.5
C_V	Speed coefficient		2.0
V	Speed, f.p.s.	Equation (3)	49.7

<u>Symbol</u>	<u>Definition</u>	<u>Where derived</u>	<u>Value</u>
V^2	Speed squared	V^2	2,470
T	Thrust, lb.	Figure 18	53,300
T_{C_M}	Thrust-moment coefficient	Equation (4)	-0.049
C_{Δ}	First approximation at load	$C_{\Delta_R} \left[1 - \left(\frac{V}{V_G} \right)^2 \right]$	0.490
τ	Trim, deg.	Figure 10	4.2
C_L	Lift coefficient	Figure 17	1.66
L	Lift, lb.	Equation (5)	27,000
Δ	Load on water, lb.	250,000 - L	222,900
C_{Δ}	Load coefficient	Equation (1)	0.490

This value of load coefficient checks the trial value. If it did not do so, the last 6 operations would be re-computed, using the last value of load coefficient as the trial load.

<u>Symbol</u>	<u>Definition</u>	<u>Where derived</u>	<u>Value</u>
C_R	Resistance coefficient	Figure 10	0.090
R	Resistance, lb.	Equation (2)	41,000
C_D	Drag coefficient	Figure 17	0.122
D	Drag, lb.	Equation (6)	2,000
R + D	Total resistance, lb.	R + D	43,000

Similar computations were made for selected speed coefficients from rest to $C_v = 3.0$, thereby giving the free-to-trim resistance of the craft up to the point where the pilot assumes control.

The trim is determined from figure 10. In that figure the moment is known and the load is assumed for an approximation. The trimming-moment-coefficient curves are entered at the positive value necessary to balance the

negative thrust-moment coefficient, and the trim is determined by interpolating between the load parameters. This trim is used to find the lift of the wings, which will give the load on the water when deducted from the gross weight. This weight should check the load assumed in the first approximation. If it does not check, then a new calculation must be made, using the computed load as the second approximation. After the load on the water has been determined, the resistance can be read from the curves by using the trim and visually interpolating between the loads or by auxiliary cross plots. The drag coefficient is found on the lift-drag curves (fig. 17), and the drag is computed from the coefficient and added to the resistance. This process is repeated for each speed coefficient.

The computations for high speeds are made at 1° increments of trim, and a trim whose resistance is lower than that of the trim on either side of it is considered best trim. This method of computation does away with the necessity of approximating the load. Both the speed and the trim being known, the load is determined. The resistance is found from the trim and the load. The drag is found and added in the usual manner. A sample calculation for a trim of 5° follows:

<u>Symbol</u>	<u>Definition</u>	<u>Where derived</u>	<u>Value</u>
C_v	Speed coefficient		4.25
V	Speed, f.p.s.	Equation (3)	105.8
V^2	Speed squared	V^2	11,200
L	Lift, lb.	Equation (7)	130,000
Δ	Load on water, lb.	$250,000 - L$	120,000
C_Δ	Load coefficient	Equation (1)	0.264
C_R	Resistance coefficient	Figure 10	0.051
R	Resistance, lb.	Equation (2)	23,200
D	Drag, lb.	Equation (8)	9,800
$R + D$	Total resistance, lb.	$R + D$	33,000

In the foregoing calculation, the lift and the drag

formulas become simply:

$$L = 6.60 \times 1.74 V^2 = 11.5 V^2 \quad (7)$$

$$D = 6.60 \times 0.133 V^2 = 0.878 V^2 \quad (8)$$

The values of 1.74 and 0.133 are the lift and the drag coefficients, respectively, at a trim of 5° (fig. 17).

Similar computations were made for 4° and 6° trim at the same speed coefficient and the value of $R + D$ at 4° was 33,900 and that at 6° was 33,300. Inasmuch as the total resistance at 5° is lower than at either 4° or 6° , 5° was considered the best trim at this speed and the results for it were plotted in figure 18. When the best trim at high speeds has been added to the free-to-trim low speeds, the dotted curve in figure 18 is the result. The air drag plotted does not include the air drag of the hull, which is included in the tank data.

Model 74-A has about the same margin of thrust at the high speeds as it has at the hump. This condition is desirable because it balances the excess thrust so as to give a more uniform accelerating force and a smaller take-off time. Neglecting the sharp peak of model 75 at the hump, which is of so short a duration as to be considered of little consequence, the hump values of the resistances of the two models are approximately the same. The low-speed and the high-speed resistances of model 75 could be changed so that the accelerating force would be a little better balanced, as in model 74-A, by using a slightly larger hull. The effect of a larger hull is to decrease the hump resistance and to increase the high-speed resistance. The use of a larger hull is not thought advisable because the air drag of model 75 is slightly higher than that of model 74-A and to make model 75 any larger would increase its air drag still more. Also, a decrease in resistance at high speeds decreases the length of run more than a corresponding decrease in resistance at a lower speed because the greater the speed, the greater the distance traveled in a given time.

The take-off time and distance were computed as shown in reference 6 and are as follows:

<u>Model</u>	<u>Time, sec.</u>	<u>Distance, ft.</u>
74-A	85	7,800
75	80.5	6,940

AERODYNAMIC TESTS

Apparatus and Procedure

The aerodynamic tests of models 74 and 75 were made in the N.A.C.A. 20-foot wind tunnel. The models were mounted in an inverted position on a strut in a manner similar to that described in reference 1. The supporting structure for these tests, however, was entirely shielded by a streamline fairing extending to within $1/8$ inch of the surface of the hull. No tare-drag tests were made and no lift measurements were taken.

The models were tested at pitch angles ranging from -6° to 13° at approximately $2-1/2^\circ$ intervals. At each pitch setting, measurements were made at 10 air speeds ranging from 45 to 110 miles per hour. At the highest speed, the Reynolds Number was approximately 10,000,000.

The part of the jet in which the models were located has a static-pressure gradient along the jet axis. In these tests, the resulting horizontal-buoyancy correction amounted to about 14 percent of the minimum drag of the hulls.

Values of measured drag were plotted against dynamic pressure, q , for each pitch angle. Values taken from these curves at an arbitrary value of q were corrected for horizontal buoyancy and then plotted in the form of drag coefficients against pitch angle.

Inasmuch as the balance was designed to cope with fluctuating loads many times the magnitude of those encountered in these tests, a calibration was made to determine its suitability. The drag scale was found to check its calibration, in general, within ± 0.1 pound with no indication of friction effects. The points on the plots of drag against dynamic pressure were, with few exceptions, within ± 0.1 pound of a straight line drawn through them. The resulting points on the curves of drag coefficient against pitch angle were mutually consistent to a degree indicating a maximum error in drag measurement of ± 0.12 pound. It is therefore thought that the balance readings are accurate to within ± 0.15 pound, or less than ± 5 percent over the range of pitch angles covered. In the region of minimum drag, the points appeared more consistent and the error may be slightly less.

Results and Discussion

The drag curves for models 74 and 75 are given in figures 19 and 20, respectively. In both of these figures the drag coefficient, $C_D = \text{drag}/qA$, is based on the maximum cross-sectional area of the model. It is possible to estimate the drag of model 74-A by assuming that the change is chiefly due to changing the depth of the step. Using the corrective factor derived in reference 1 and assuming it to be valid at other angles of pitch, the drag coefficient of model 74-A is found to be greater than that of model 74 by 0.003. The resulting curve is included in figure 19. The true drag curve for model 74-A probably lies somewhere between the two curves of figure 19.

The minimum drag coefficient based on cross-sectional area is seen to be 0.092 for model 74-A and 0.094 for model 75. In both cases, minimum drag occurs at a pitch angle of about -1° . Using a drag coefficient based on the two-thirds power of the volume, the value is 0.0325 for model 74-A and 0.0342 for model 75. The minimum drag coefficients of the two models based on the cross-sectional area therefore differ by 2.2 percent, but the minimum drag coefficients based on $(\text{volume})^{2/3}$ differ by 5.2 percent.

From a comparison of the data of reference 1 and these tests, it might appear that models 74-A and 75 do not represent much of an improvement over N.A.C.A. models 11-A and 26 as far as minimum drag is concerned. The minimum drag coefficient of model 26 is the same as that of model 74-A and lower than that of model 75. The minimum drag coefficients of models 74-A and 75 based on the two-thirds power of the volume, however, are lower than any reported in reference 1.

For a specific design problem, the size of the hull may be governed by the necessity of having certain seaworthiness and take-off characteristics and enough space for the suitable accommodation of the useful load. It is necessary, therefore, to make a detailed analysis of each case in order to determine the relative merits of different hull forms on the basis of drag.

The models of the present investigation have their minimum drag occurring at a lower pitch angle than either model 11-A or model 26. The computation of take-off performance has already shown this feature to be a definite

advantage. Models 11-A and 26 are of a lower fineness ratio than the models of this investigation and do not have a comparable extension for the support of the tail surfaces. At pitch angles other than that of minimum drag, models 74-A and 75 are seen to be of merit in that their drag increases less with pitch angle than the drag of any of the models of reference 1.

CONCLUDING REMARKS

The present tests illustrate how the aerodynamic drag of a flying-boat hull may be reduced by following closely the form of a low-drag aerodynamic body and also the manner in which the extent of the aerodynamic refinement is limited by poorer hydrodynamic performance. This limit is not sharply defined but is first evidenced by an abnormal flow of water over certain parts of the form accompanied by a sharp increase in resistance, i.e., "sticking." In the case of models 74-A and 75, the sticking occurs only at certain combinations of speed, load, and trim and can be avoided by proper control of the trim at high water speeds.

Model 75 has higher water resistance at low speeds and lower resistance at very high speeds than does model 74-A. With constant-speed propellers and high take-off speeds, it appears that the form of model 75 would give slightly better take-off performance. Model 74-A, however, has lower aerodynamic drag than does model 75 for the same volume of hull.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 20, 1938.

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3. Dawson, John R.: Tank Tests of Three Models of Flying-Boat Hulls of the Pointed-Step Type with Different Angles of Dead Rise - N.A.C.A. Model 35 Series. T.N. No. 551, N.A.C.A., 1936.
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6. Shoemaker, James M., and Parkinson, John B.: A Complete Tank Test of a Model of a Flying-Boat Hull - N.A.C.A. Model No. 11. T.N. No. 464, N.A.C.A., 1933.

TABLE I
OFFSETS FOR N.A.C.A. MODEL 74-A
[Inches]

Station	Dis- tance from P.P.	Distance from base line										D	Half-breadth			Radii			
		K	CH	TH	B ₁ 1.00 ^a	B ₂ 2.00 ^a	B ₃ 3.00 ^a	B ₄ 4.00 ^a	B ₅ 5.00 ^a	B ₆ 6.00 ^a	B ₇ 7.00 ^a		CB	TB	RB	R ₁	R ₂	R ₃	R ₄
1	0.60		0.73	1.02								0	1.07	0.71		1.24	1.24	-3.63	-1.65
2	2.85		1.96	2.49								0	2.86	1.74		3.04	3.04	3.80	10.76
3	5.10		2.79	3.41								0	4.07	2.38		4.16	4.16	3.57	43.3
4	9.60		3.88	4.65								0	5.67	3.24		5.67	5.67	4.30	↑
5	14.10		4.54	5.44								0	6.63	3.79		6.63	6.63	5.01	
6	18.60		4.95	5.92								0	7.22	4.13		7.22	7.22	5.43	
7	23.10		5.21	6.24								0	7.61	4.35		7.61	7.61	5.76	
8	27.60		5.35	6.40								0	7.81	4.47		7.81	7.81	5.89	offsets
9	32.10		5.43	6.50								0	7.93	4.54		7.93	7.93	6.00	
10	36.60		5.52	6.59								0	7.96	4.60		7.96	8.04	6.00	
11	41.10		5.61	6.68								0	7.96	4.66		7.94	8.15	6.01	
12	45.60		5.70	6.77								0	7.87	4.72		7.87	8.26	6.05	
F	50.10		5.82	6.88								.02	7.75	4.80		7.75	8.39	6.15	v
13 A	50.10		5.51	6.36								.02	7.75	4.62		7.75	8.08	6.46	
14	54.60	7.73	5.25		7.64	7.44	7.10	6.62	6.08	5.64	5.34	.09	7.52		8.02	7.58			
15	59.10	7.42	5.06		7.30	7.08	6.74	6.29	5.80	5.39	5.09	.20	7.14		7.64	7.37			
16	63.60	7.16	5.03		7.01	6.78	6.43	6.01	5.57	5.19		.36	6.53		7.03	7.11			
17	68.10	6.94	5.14		6.76	6.52	6.17	5.77	5.38			.56	6.65		6.15	6.80			
18	72.60	6.76	5.40		6.55	6.30	5.95	5.58				.80	4.49		4.99	6.45			
19	77.10	6.63	5.80		6.40	6.13						1.09	2.96		3.46	6.05			
20	81.60	6.54	6.29		6.29							1.42	1.02		1.52	5.61			
21	83.33	6.52	6.52									1.56	0		.65	5.43			
22	86.10	5.59										1.80				5.12			
23	90.60	4.73										2.22				4.59			
24	95.10	4.02										2.69				4.10			
25	99.60	3.39										3.20				3.39			
26	104.10	2.73										3.75				2.73			
27	108.60	2.03										4.34				2.03			
28	112.80	1.23										4.96				1.23			
29	114.00	.87										5.14				.87			
30	114.60	.51										5.23				.51			
A.P.	114.85	0										5.27				0			

^aDistance of buttocks from center line.

TABLE II
OFFSETS FOR N.A.C.A. MODEL 75
[Inches]

Station	Dis- tance from F.P.	Distance from base line										Half-breadth						Radial		
		A	C	B	F	B ₁ 1.40 ^a	B ₂ 2.80 ^a	B ₃ 4.20 ^a	B ₄ 5.60 ^a	B ₅ 7.00 ^a	G	E	D	WL ₁ 7.00 ^b	WL ₂ 5.60 ^b	WL ₃ 4.20 ^b	WL ₄ 2.80 ^b	WL ₅ 1.40 ^b	R ₁	R ₂
1	0.60	1.24	0.82	0.96							0	1.15	0.80						1.24	0.55
2	2.85	3.04	2.01	2.34							0	2.86	1.96					2.95	3.04	1.40
3	5.10	4.16	2.75	3.20							0	3.90	2.67					4.07	4.16	1.90
4	9.60	5.67	3.74	4.35							0	5.31	3.63				5.45	5.59	5.67	2.60
5	14.10	6.63	4.35	5.09							0	6.21	4.25			6.24	6.42	6.56	6.63	3.05
6	18.60	7.32	4.82	5.54		7.13	6.63	5.86	5.03		0	6.87	4.64			6.94	7.06	7.17	7.22	
7	23.10	7.85	5.16	5.88		7.61	7.10	6.35	5.51	5.16	0	7.35	4.93			7.43	7.50	7.57	7.61	
8	27.60	8.25	5.46	6.16		7.95	7.41	6.72	5.94	5.53	0	7.67	5.16			7.73	7.78	7.80	7.81	
9	32.10	8.57	5.73	6.42		8.18	7.64	7.00	6.32	5.84	0	7.88	5.37			7.90	7.91	7.92	7.93	
10	36.60	8.82	5.94	6.63		8.35	7.82	7.24	6.62	6.12	0	7.96	5.55			7.96	7.96	7.96	7.96	
11	41.10	9.01	6.22	6.83	5.97	8.50	7.98	7.44	6.87	6.38	0	7.68	5.70	5.30	7.71	7.81	7.90	7.94	7.95	
12	45.60	9.16	6.68	7.00	6.43	8.64	8.14	7.60	7.09	6.06	0	6.83	5.84	5.84	7.16	7.51	7.69	7.81	7.87	
13	50.10	9.27	7.36		7.11	8.77	8.26	7.75	6.77	4.25	.02	5.34		5.43	6.41	7.02	7.39	7.62	7.75	
14	54.60	9.39	8.29		8.04	8.89	8.38	7.02	5.48	2.96	.09	3.09		4.23	5.51	6.45	7.06	7.42	7.58	
15	59.10	9.25	9.50	9.50	9.25						.20	0			Straight				7.37	
16	63.60	7.50	4.43			6.81	6.07	5.26			.36	5.45							7.11	
17	68.10	6.73	4.54			6.18	5.63	5.03			.56	5.24							6.81	
18	72.60	6.47	4.73			Straight					.80	4.75							6.45	
19	77.10	6.44	5.02			Straight					1.09	3.92							6.05	
20	81.60	5.51				Straight					1.42	2.56							5.61	
21	83.33	5.78				Straight					1.56	1.80							5.43	
22	86.10	6.44	6.44			Straight					1.80	0							5.13	
22½	88.35	4.43				3.48	2.12				2.00				.44	2.13			4.88	
23	90.60	3.03				2.54	1.44				2.23					.94			4.59	
24	95.10										2.69								4.01	
25	99.60										3.20								3.39	
26	104.10										3.75								2.73	
27	108.60										4.34								2.03	
28	112.80										4.96								1.23	
29	114.00										5.14								.87	
30	114.60										5.23								.51	
A.P.	114.85										5.27								0	

^aDistance of buttocks from center line.^bDistance of water lines from base line.

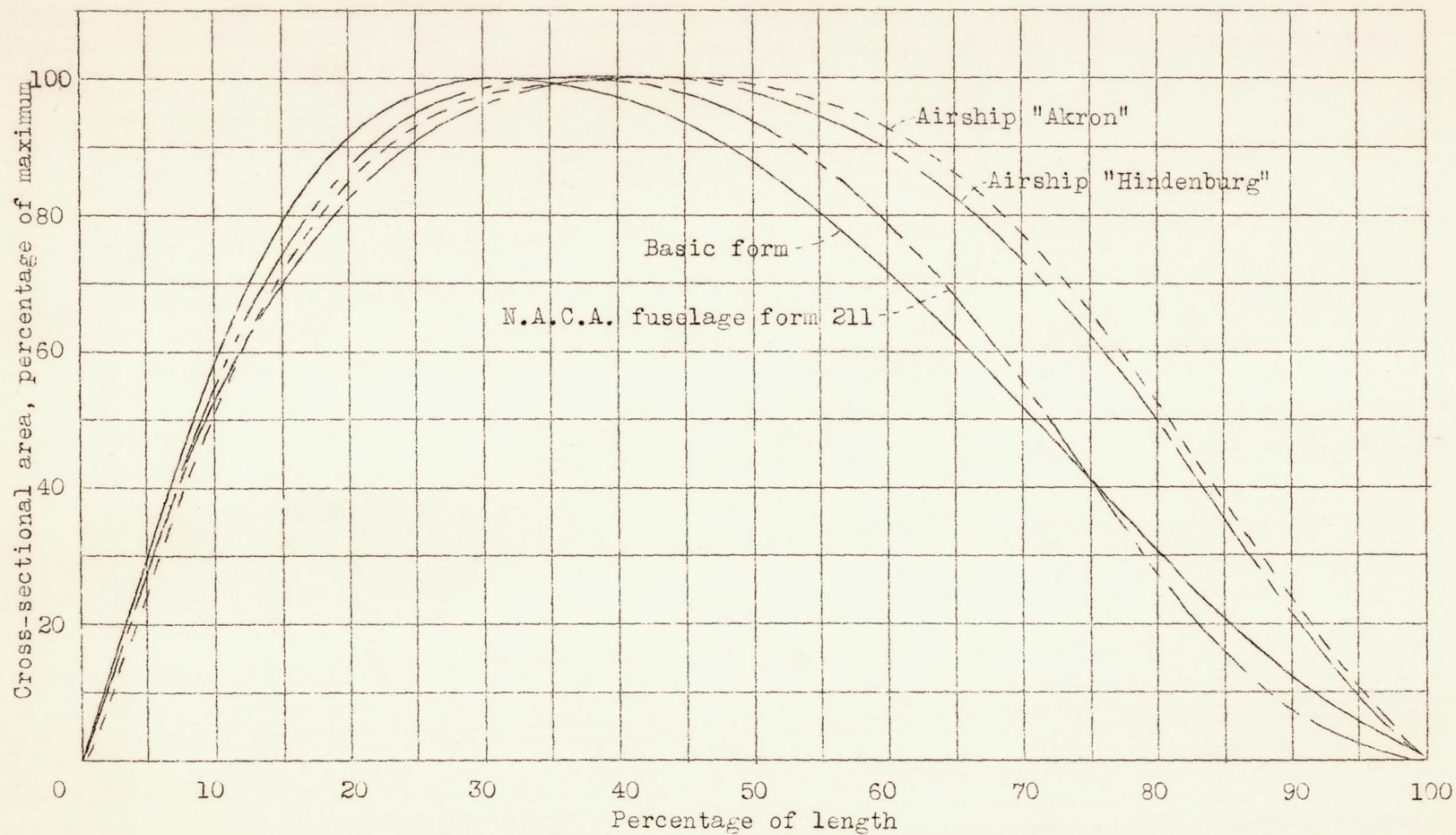


Figure 1.- Distribution of volume of basic streamline form as compared with typical airship forms and with N.A.C.A. fuselage form 211.

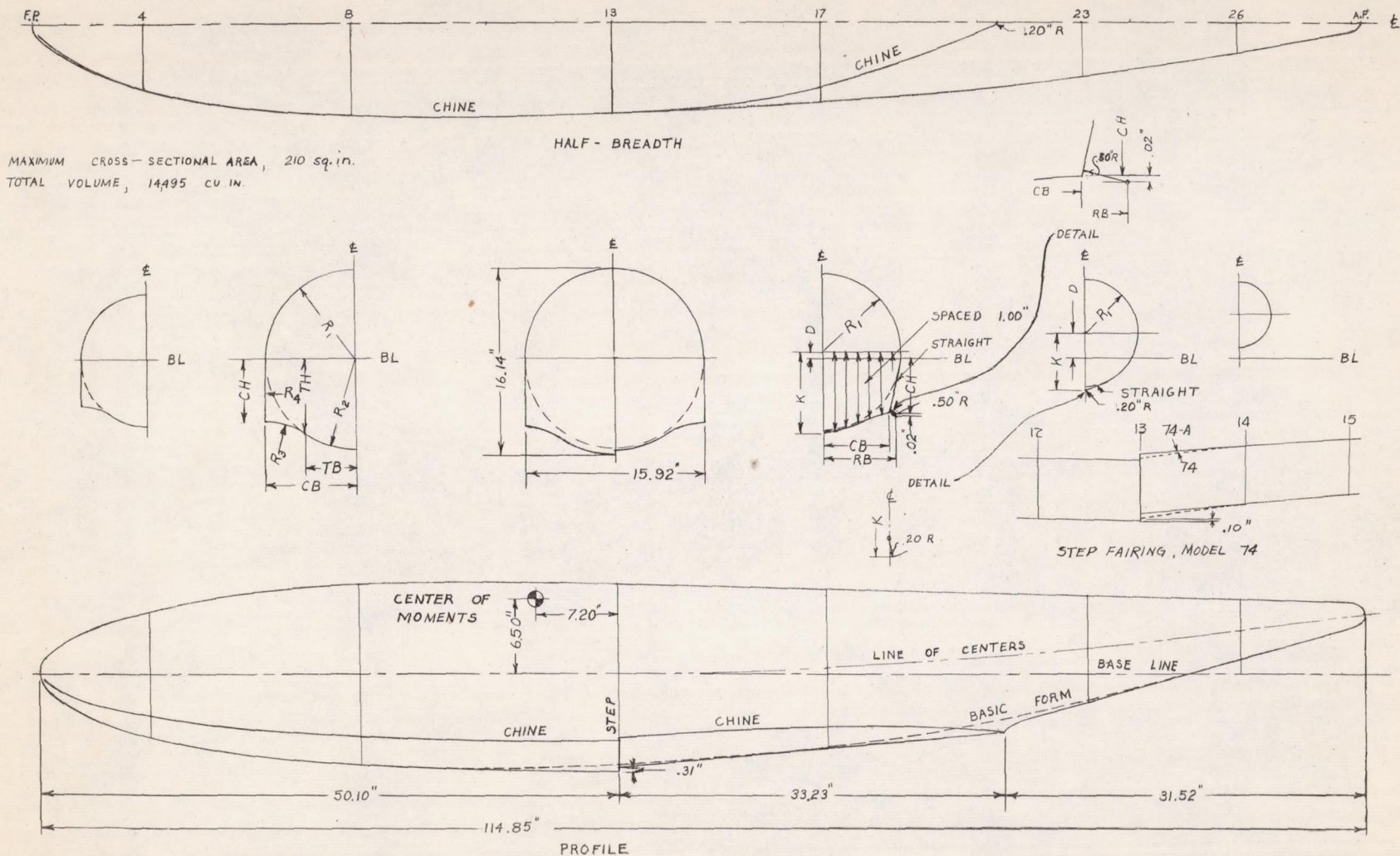


Fig. 2.- Lines of NACA. models 74 and 74-A.

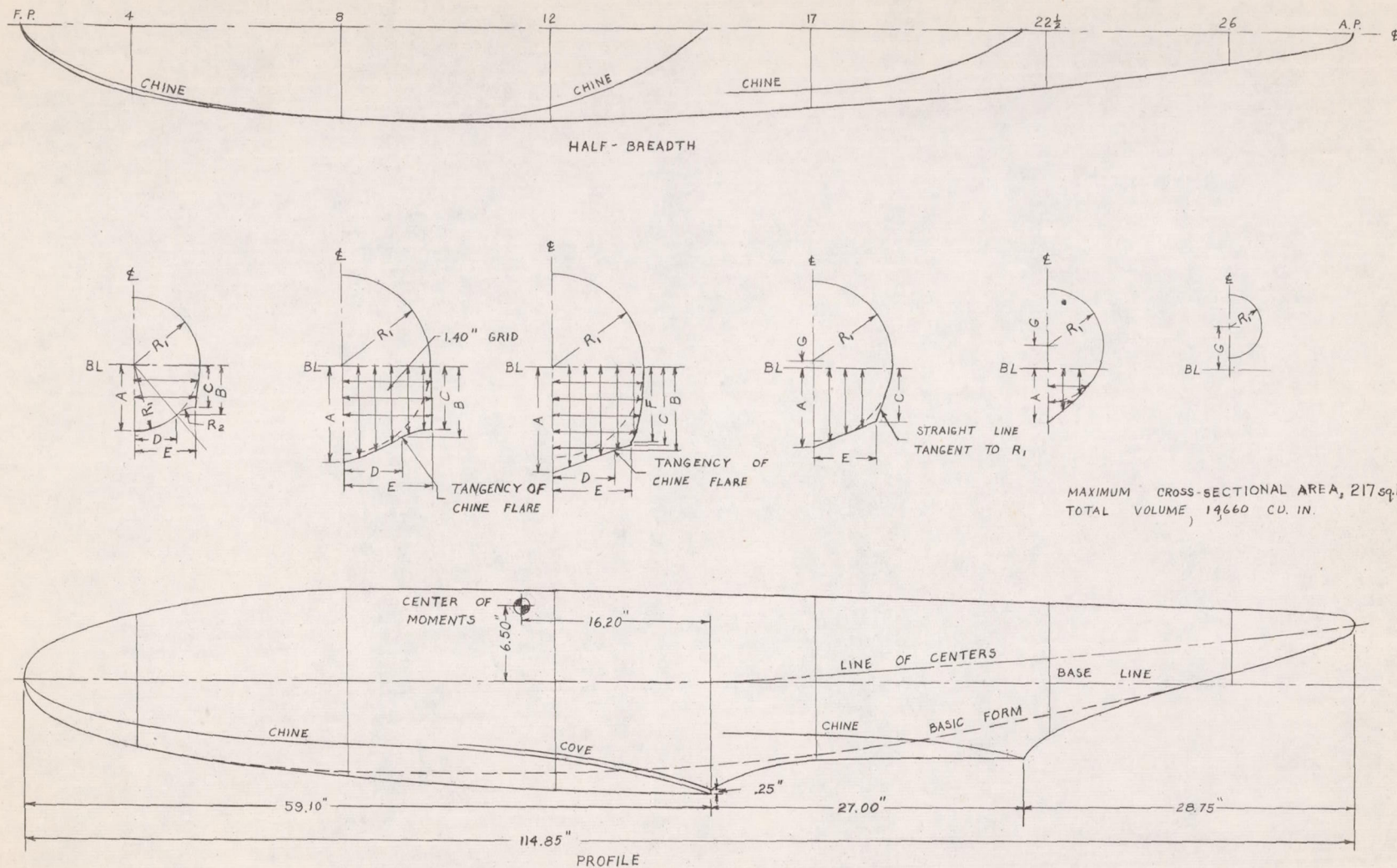


Fig. 3.-Lines of N.A.C.A. model 75.

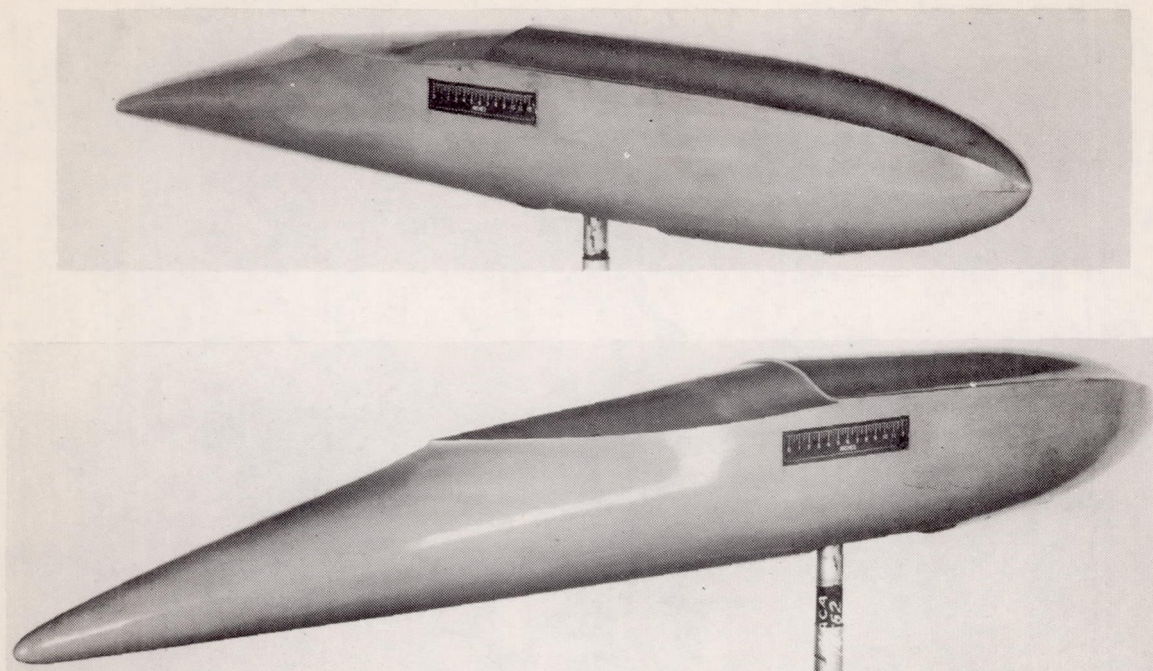


Figure 4. - Model 74-A

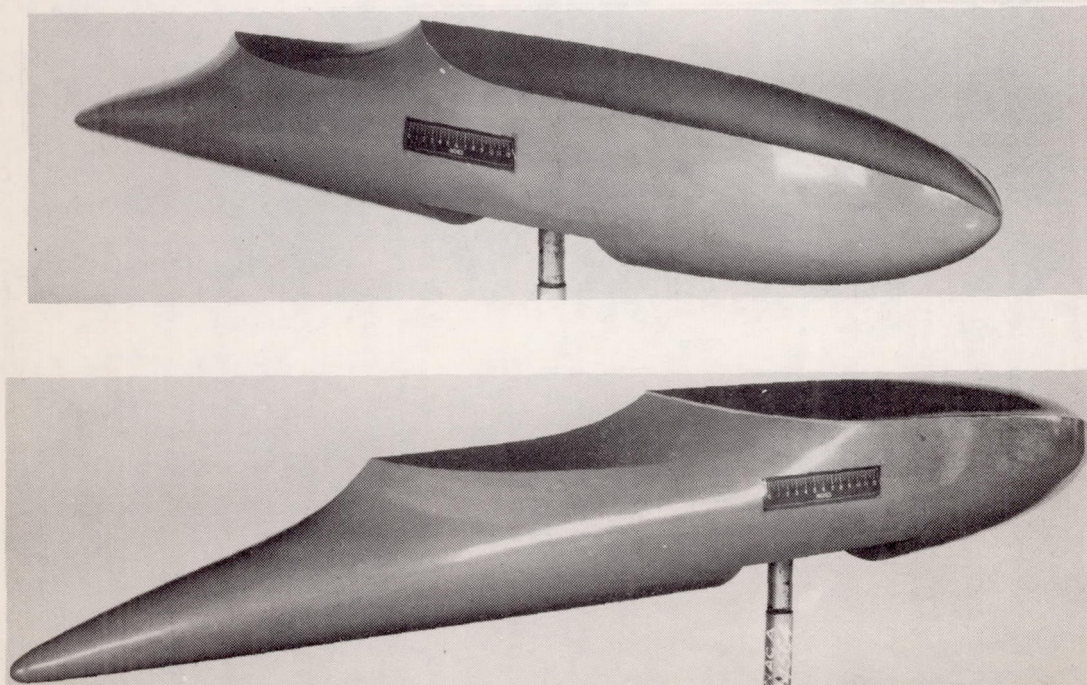
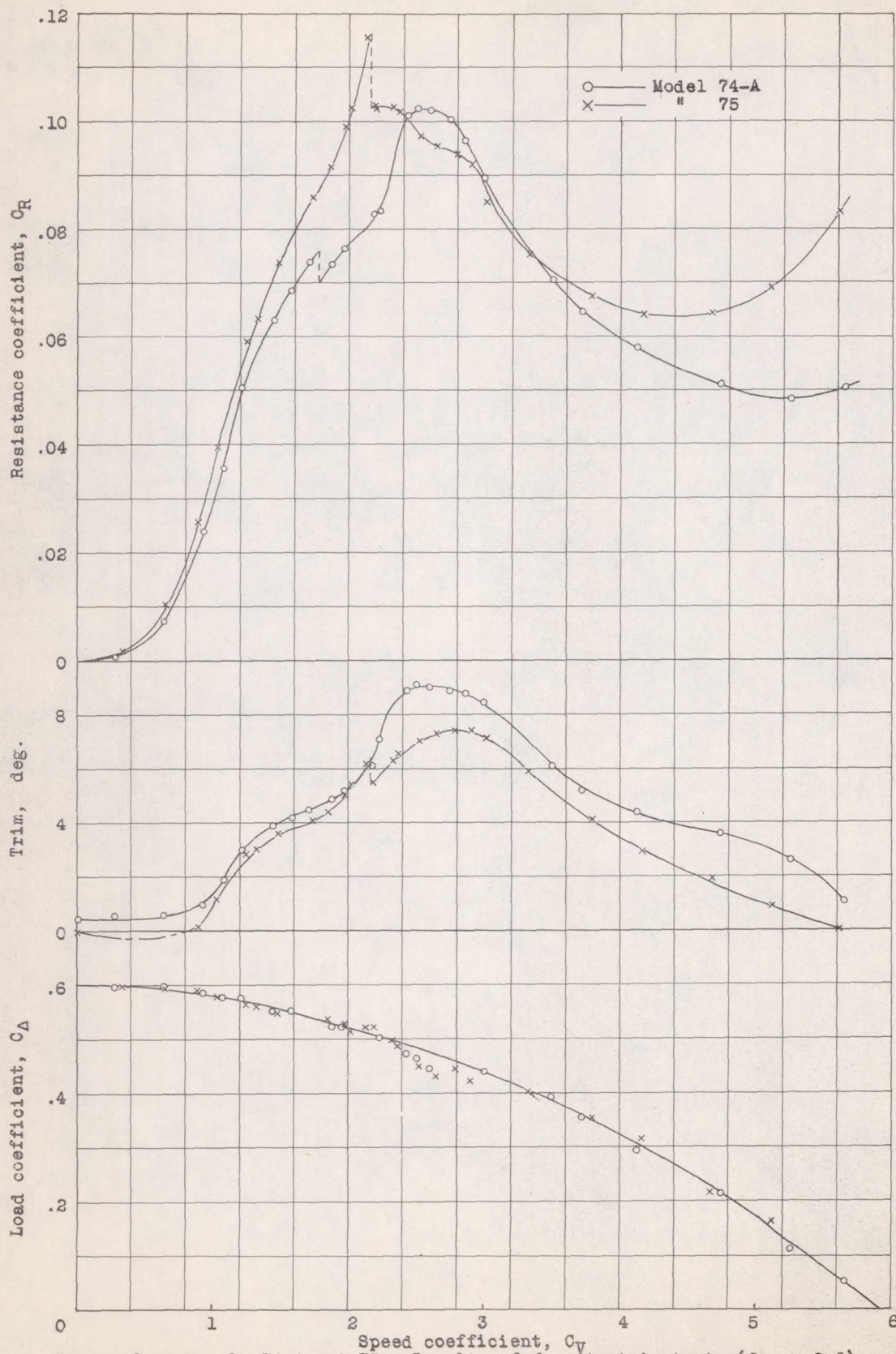
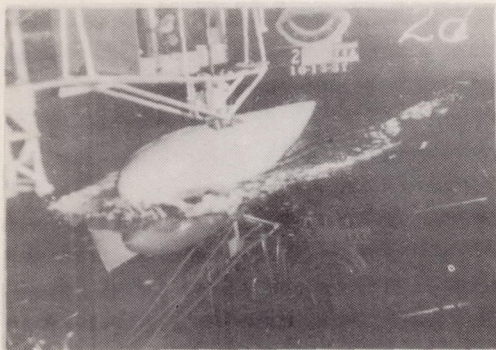
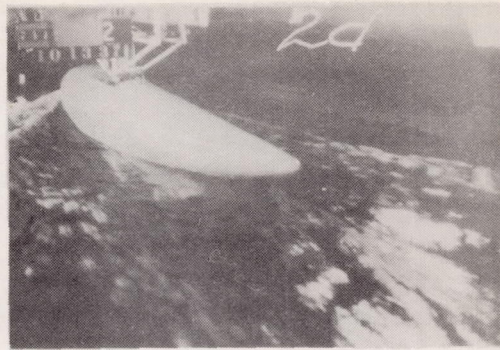


Figure 5. - Model 75

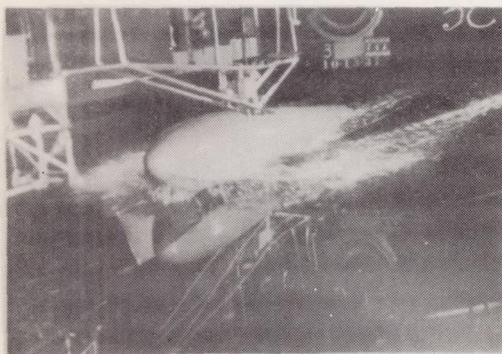
Figure 6. - Models 74-A and 75. Results of free-to-trim tests ($C_{\Delta_0} = 0.6$)



$$C_V = 1.04$$



$$\tau = 1.9^\circ$$



$$C_V = 1.97$$



$$\tau = 5.2^\circ$$



$$C_V = 2.23$$



$$\tau = 7.1^\circ$$

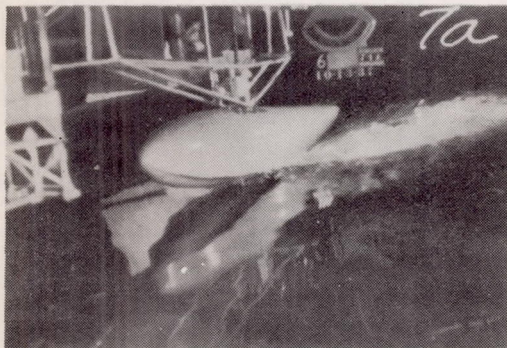
Figure 7(a). - Spray photographs of model 74-A free-to-trim.



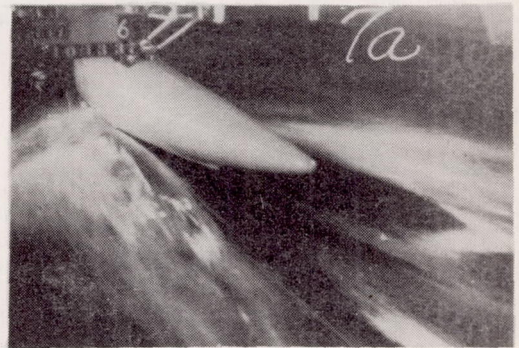
$C_V = 2.75$



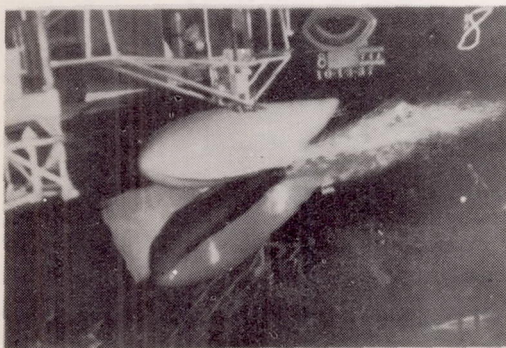
$\tau = 8.9^\circ$



$C_V = 3.72$



$\tau = 5.2^\circ$



$C_V = 4.74$

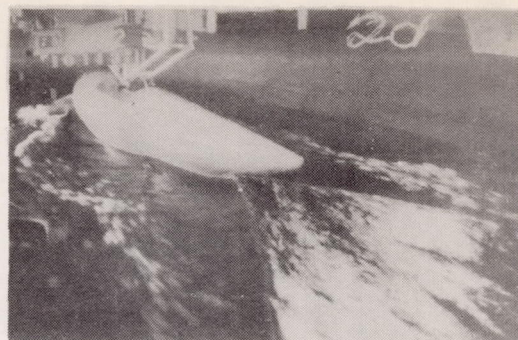


$\tau = 3.6^\circ$

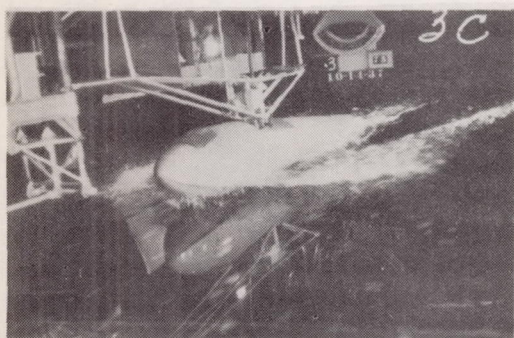
Figure 7(b). - Spray photographs of model 74-a free-to-trim.



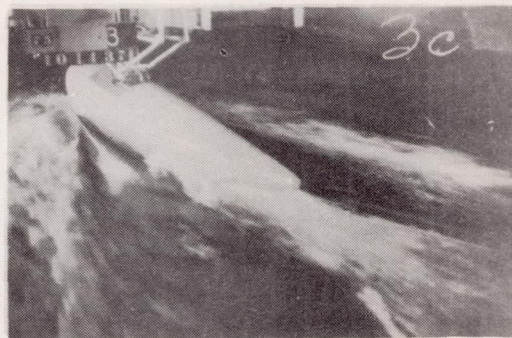
$C_V = 1.04$



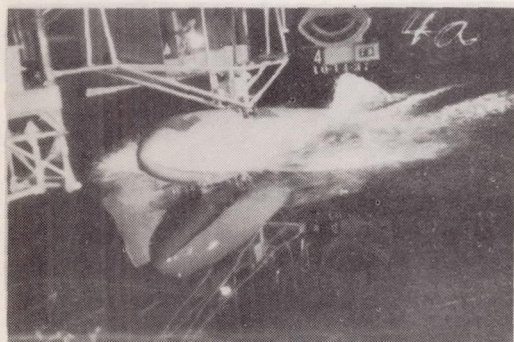
$\tau = 1.2^\circ$



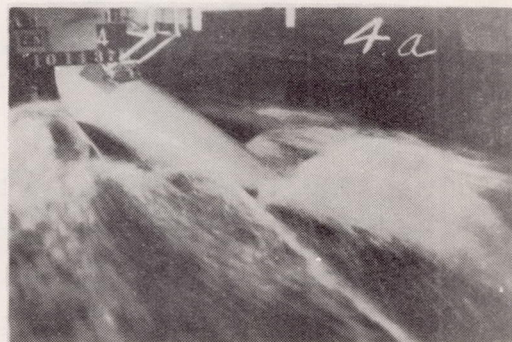
$C_V = 1.98$



$\tau = 5.0^\circ$

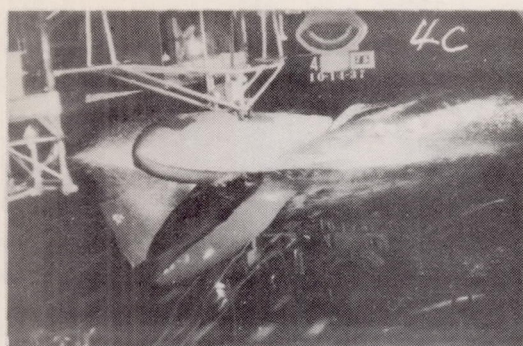


$C_V = 2.33$



$\tau = 6.3^\circ$

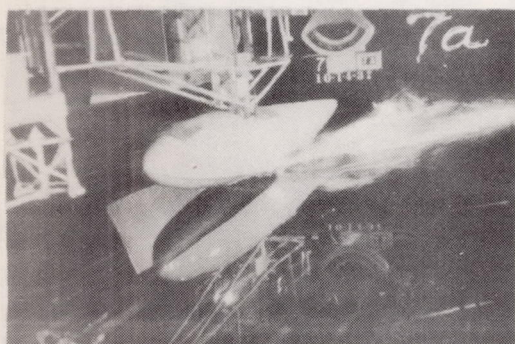
Figure 8(a).— Spray photographs of model 75 free-to-trim.



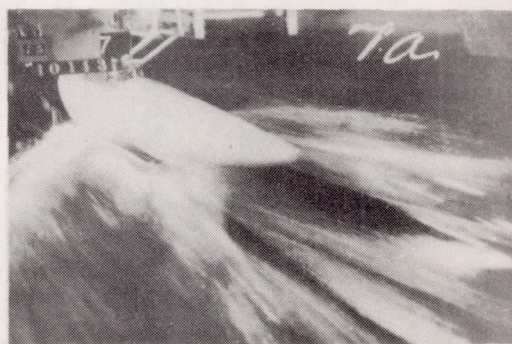
$$C_V = 2.66$$



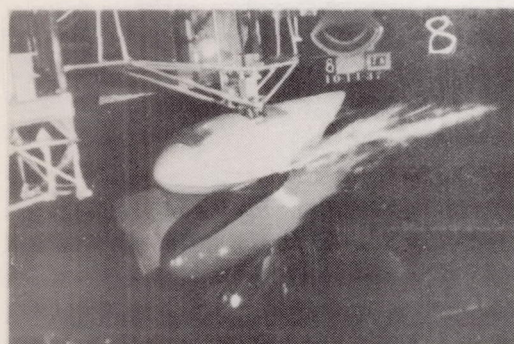
$$\tau = 7.3^\circ$$



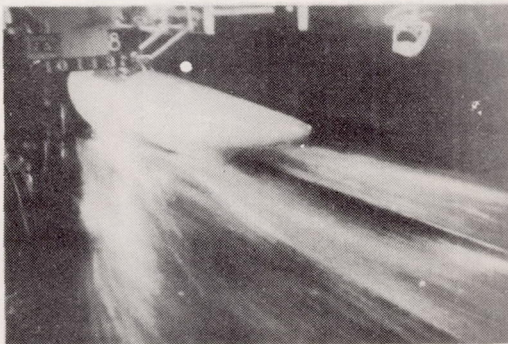
$$C_V = 4.17$$



$$\tau = 2.9^\circ$$



$$C_V = 5.12$$



$$\tau = 0.9^\circ$$

Figure 8(b).- Spray photographs of model 75 free-to-trim.

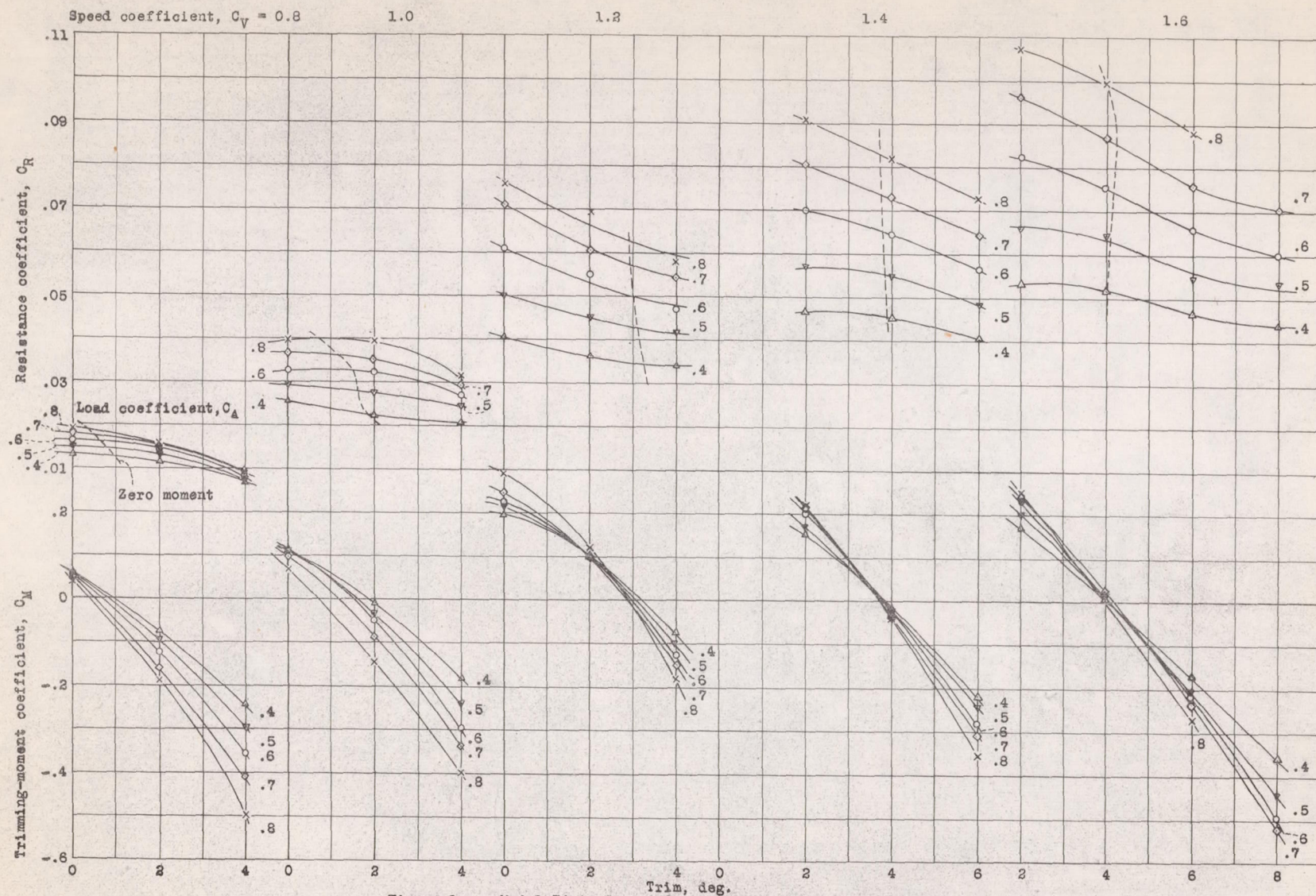


Figure 9a. - Model 74-A. C_R and C_M against trim. $C_V = 0.8, 1.0, 1.2, 1.4$ and 1.6

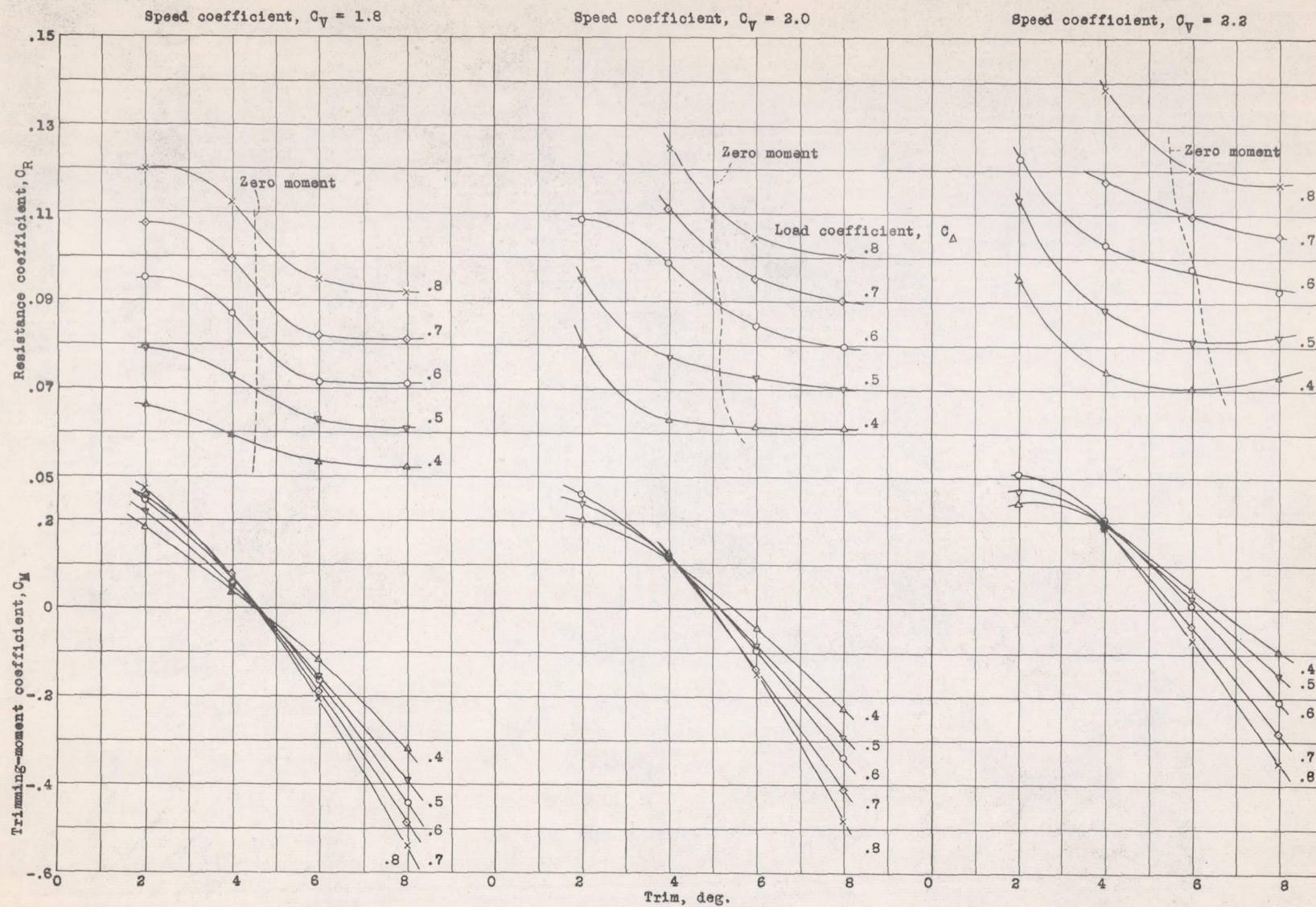


Figure 9b. - Model 74-A

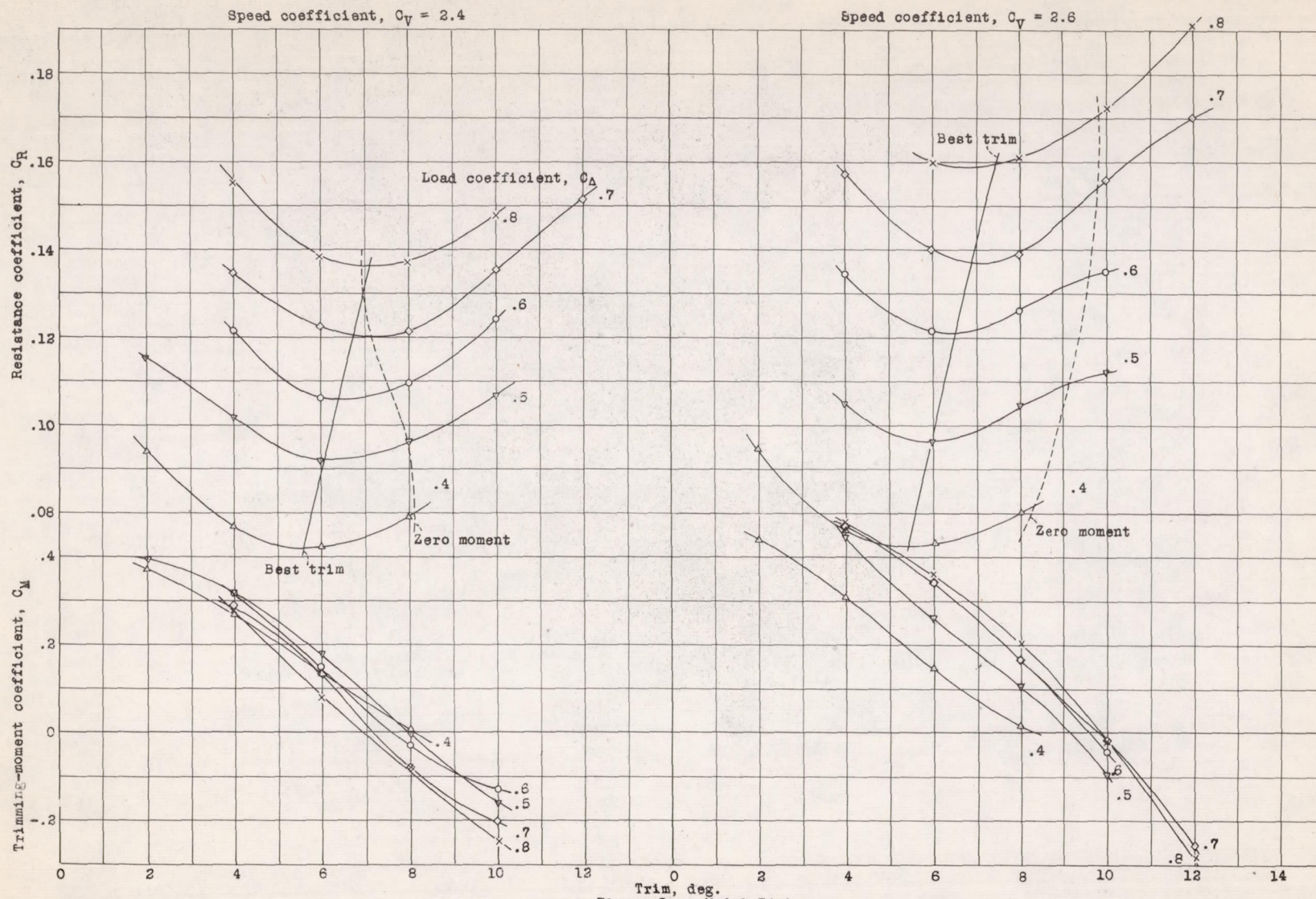
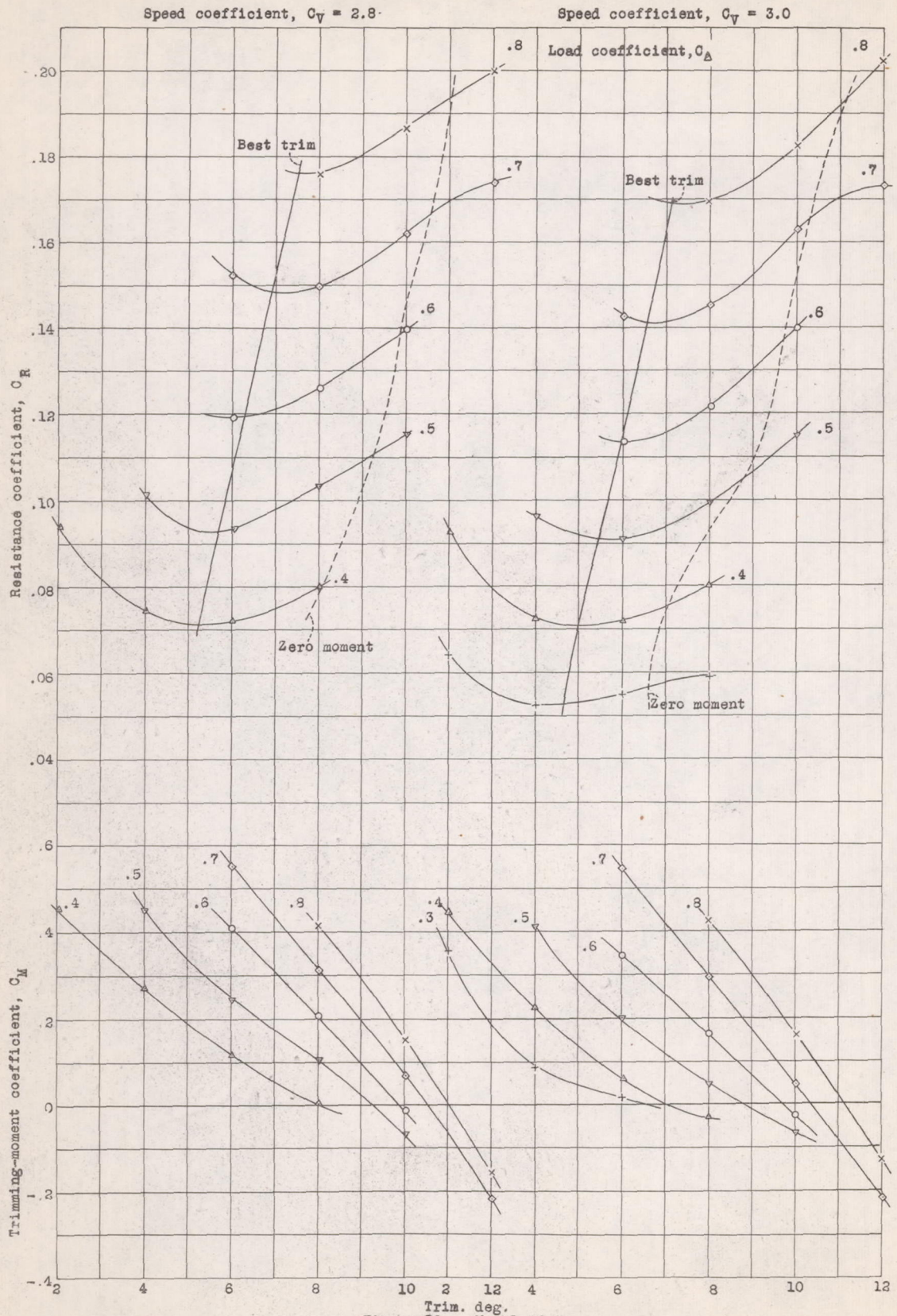


Figure 9c. - Model 74-A



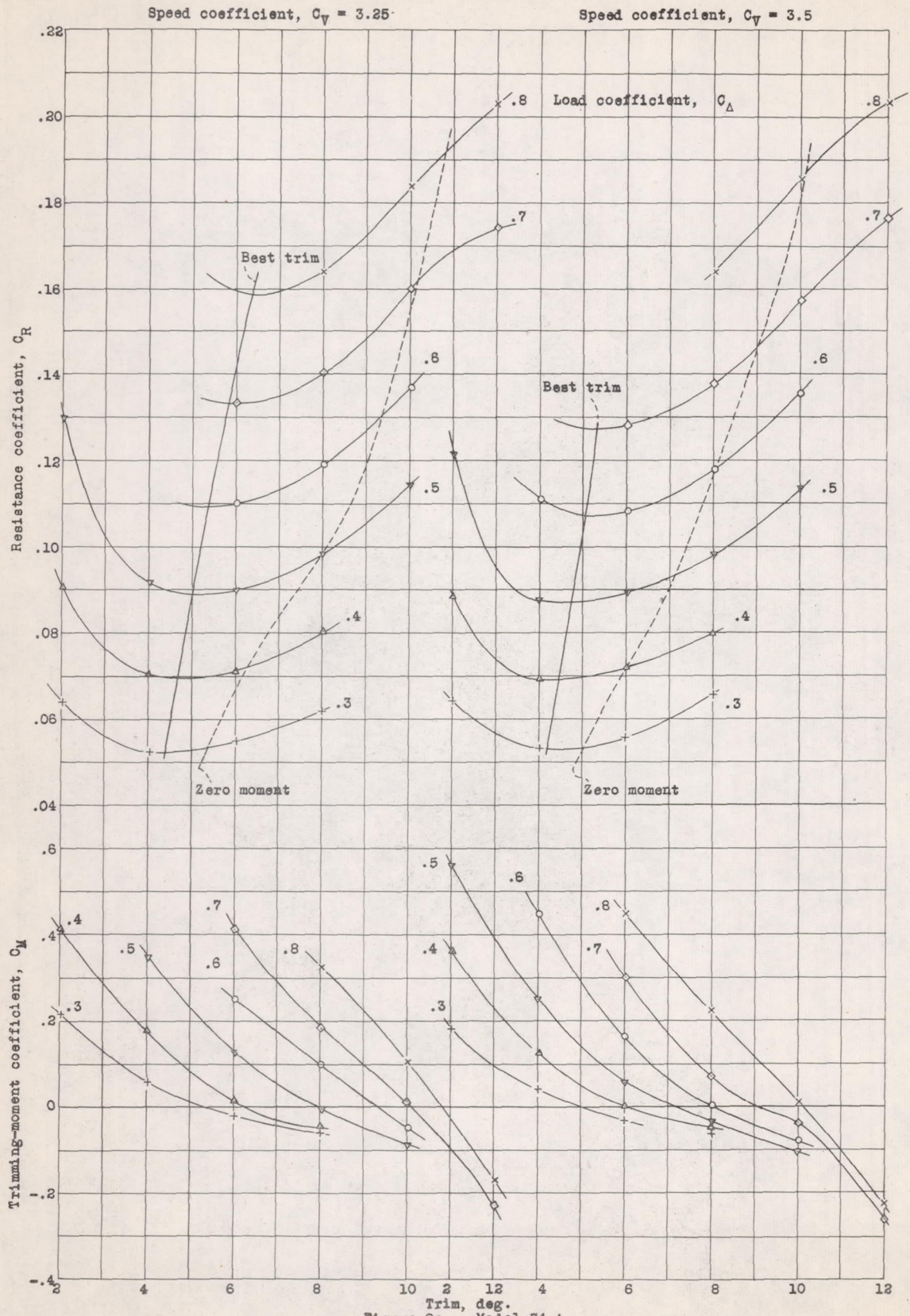


Figure 9e. - Model 74-A.

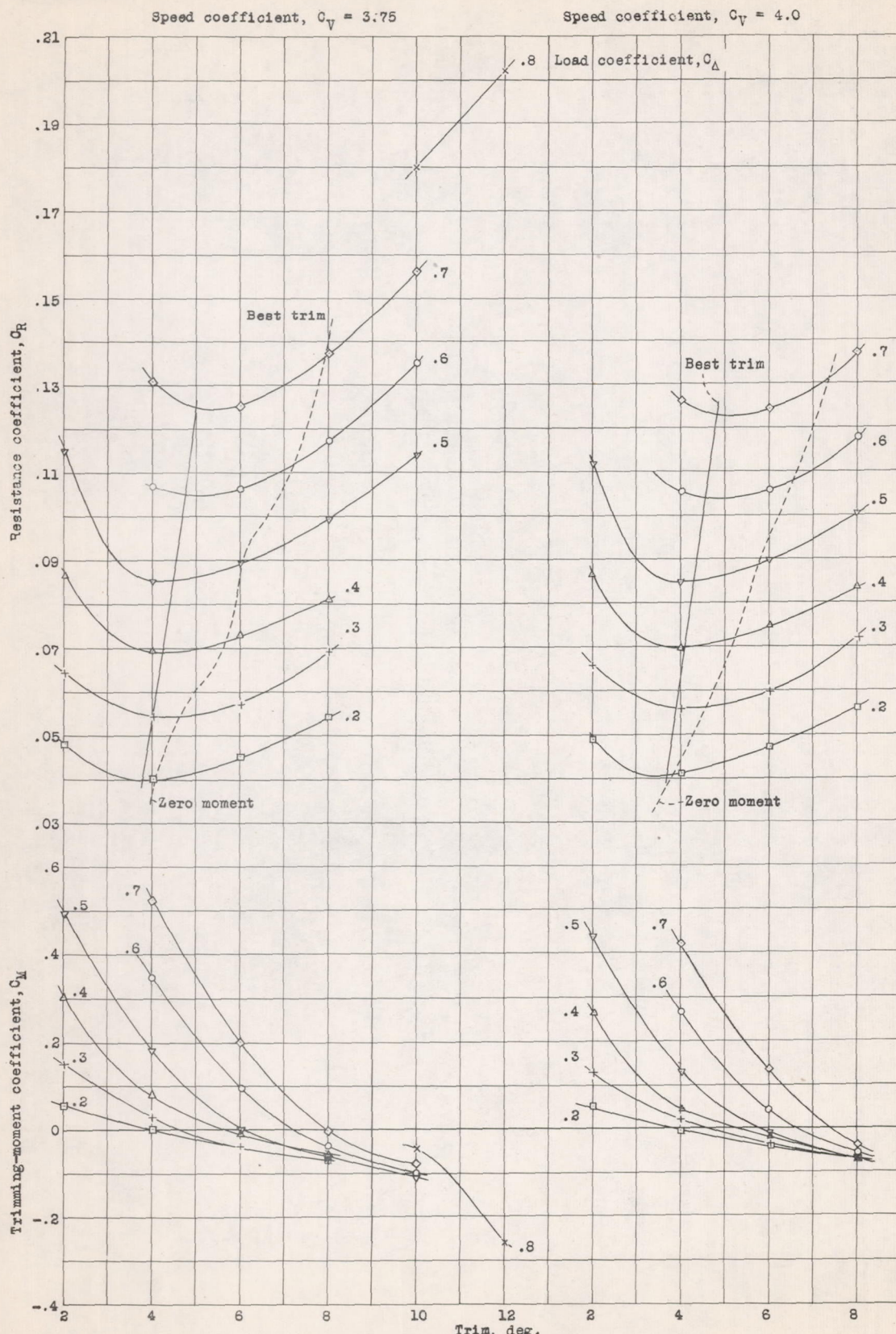
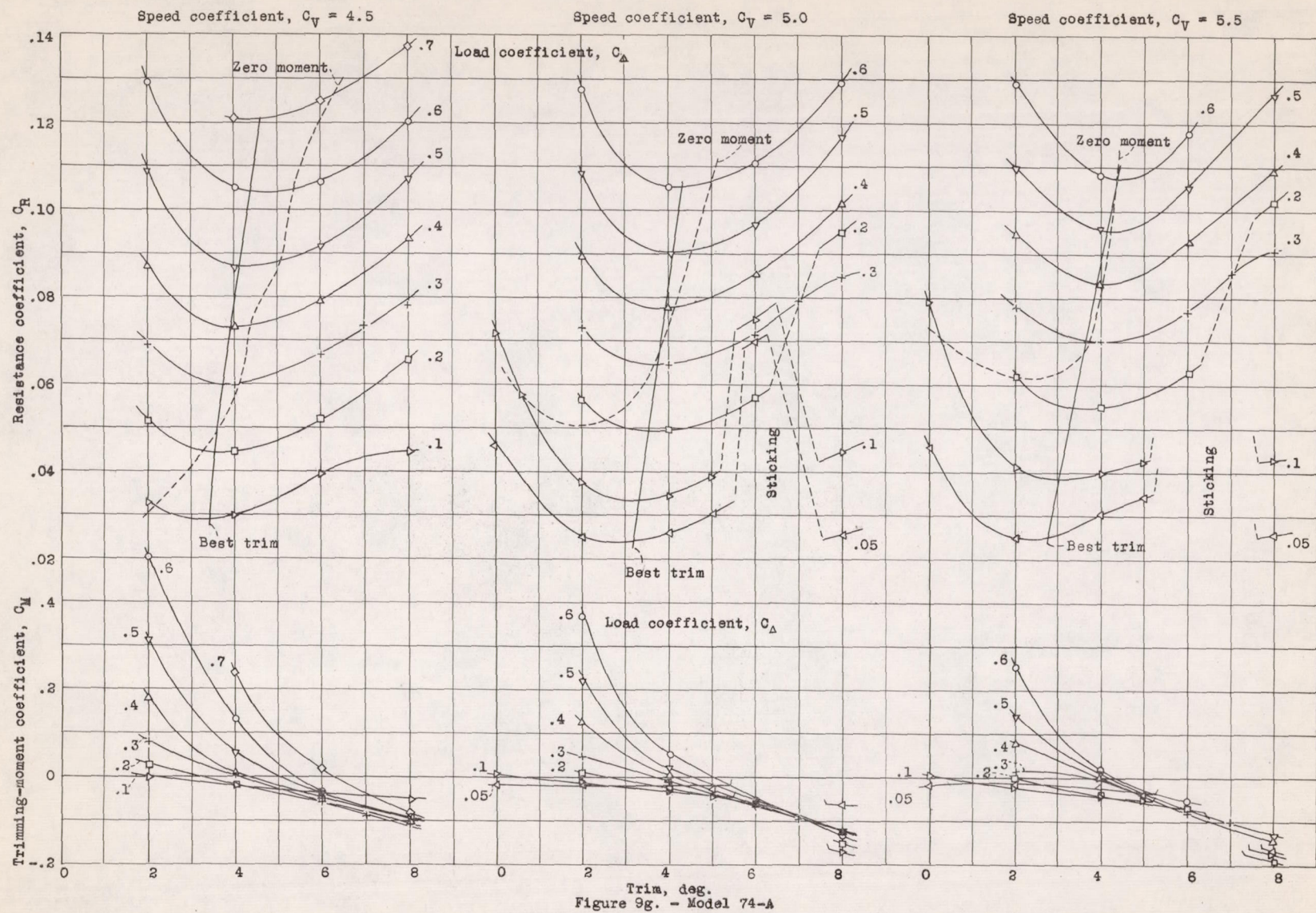


Figure 9f. - Model 74-A.



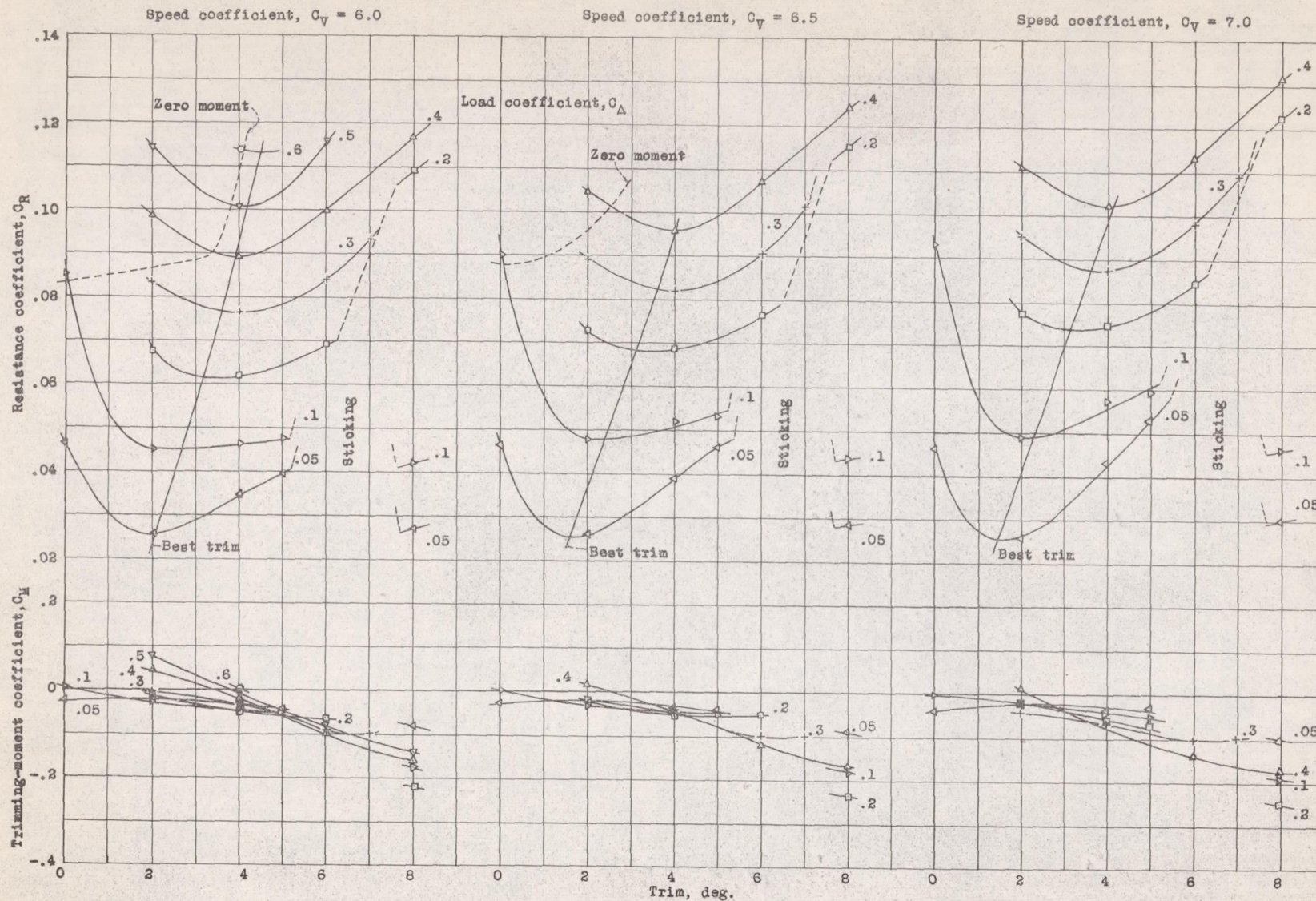


Figure 9h. - Model 74-A.

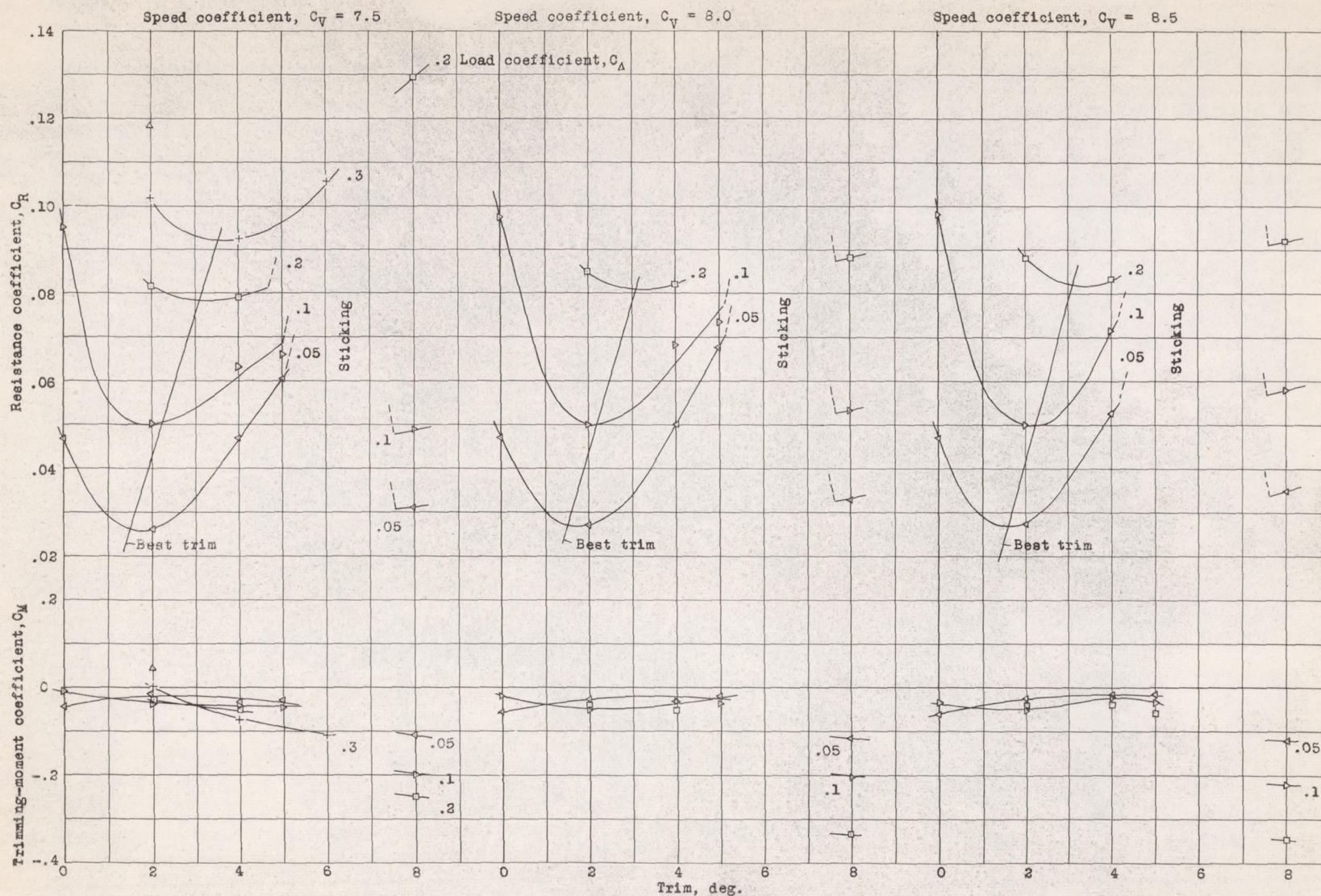


Figure 91. - Model 74-A

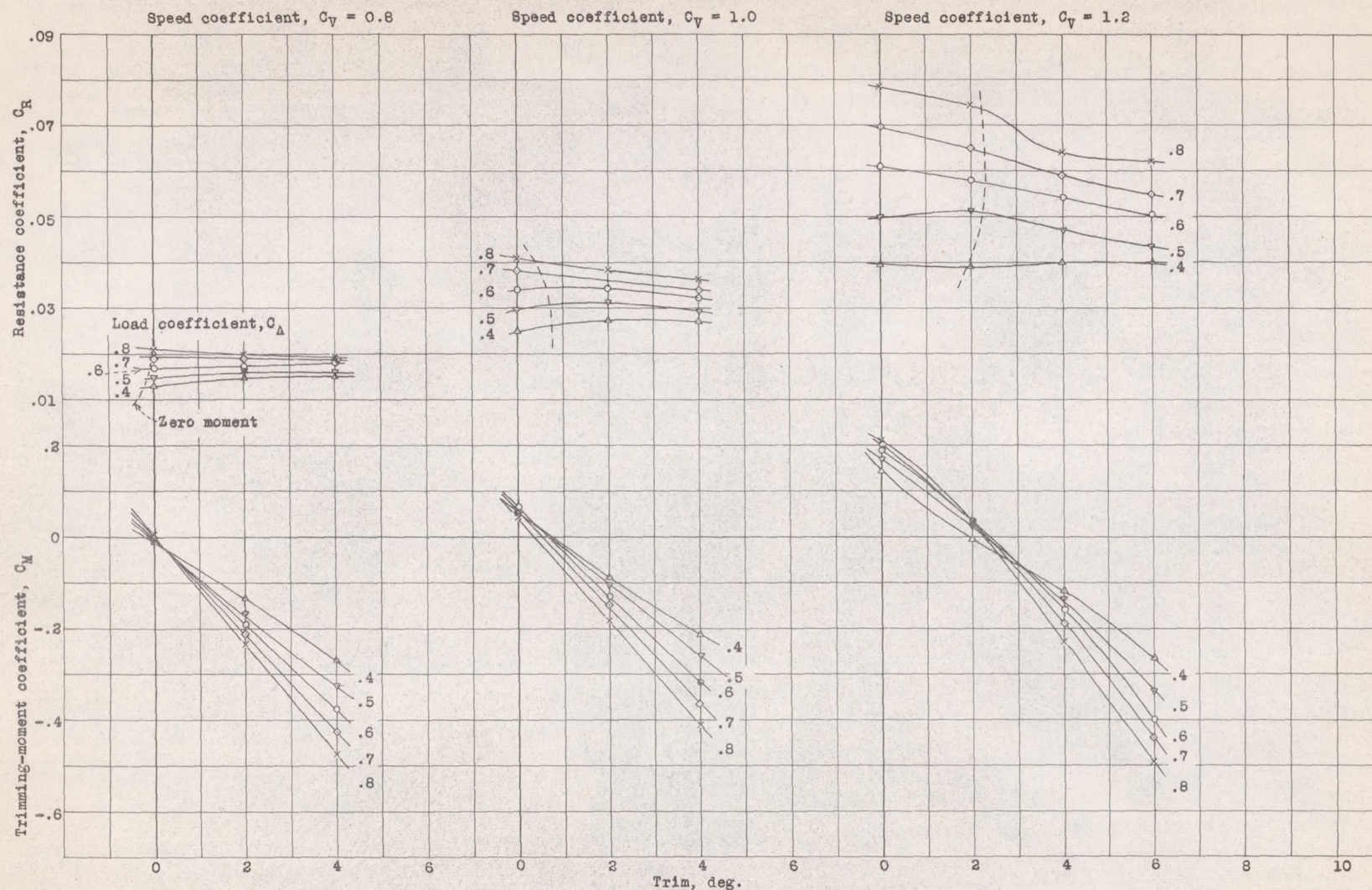


Figure 10 a . - Model 75. C_R and C_M against trim. $C_V = 0.8, 1.0$, and 1.2 .

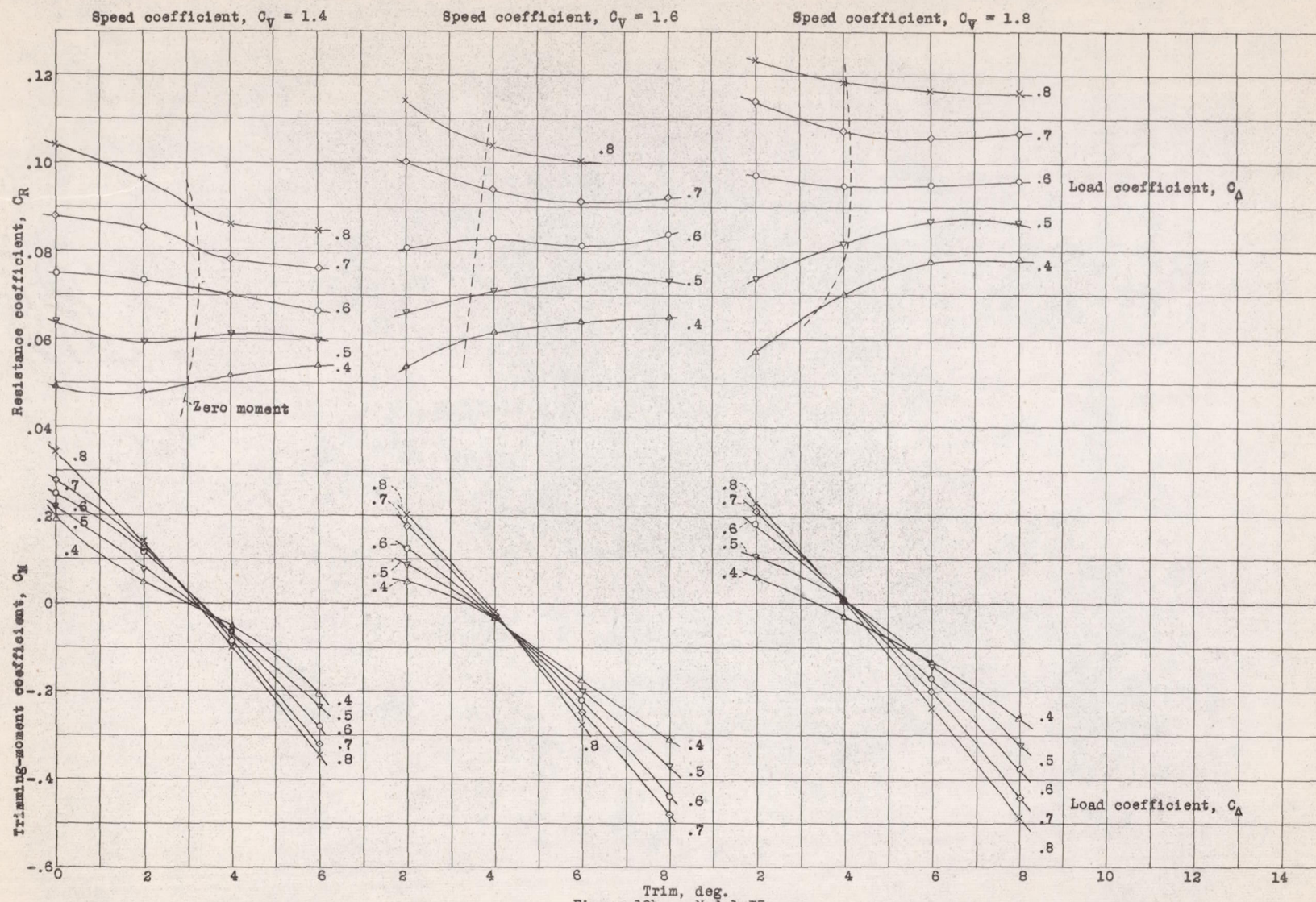


Figure 10b. - Model 75.

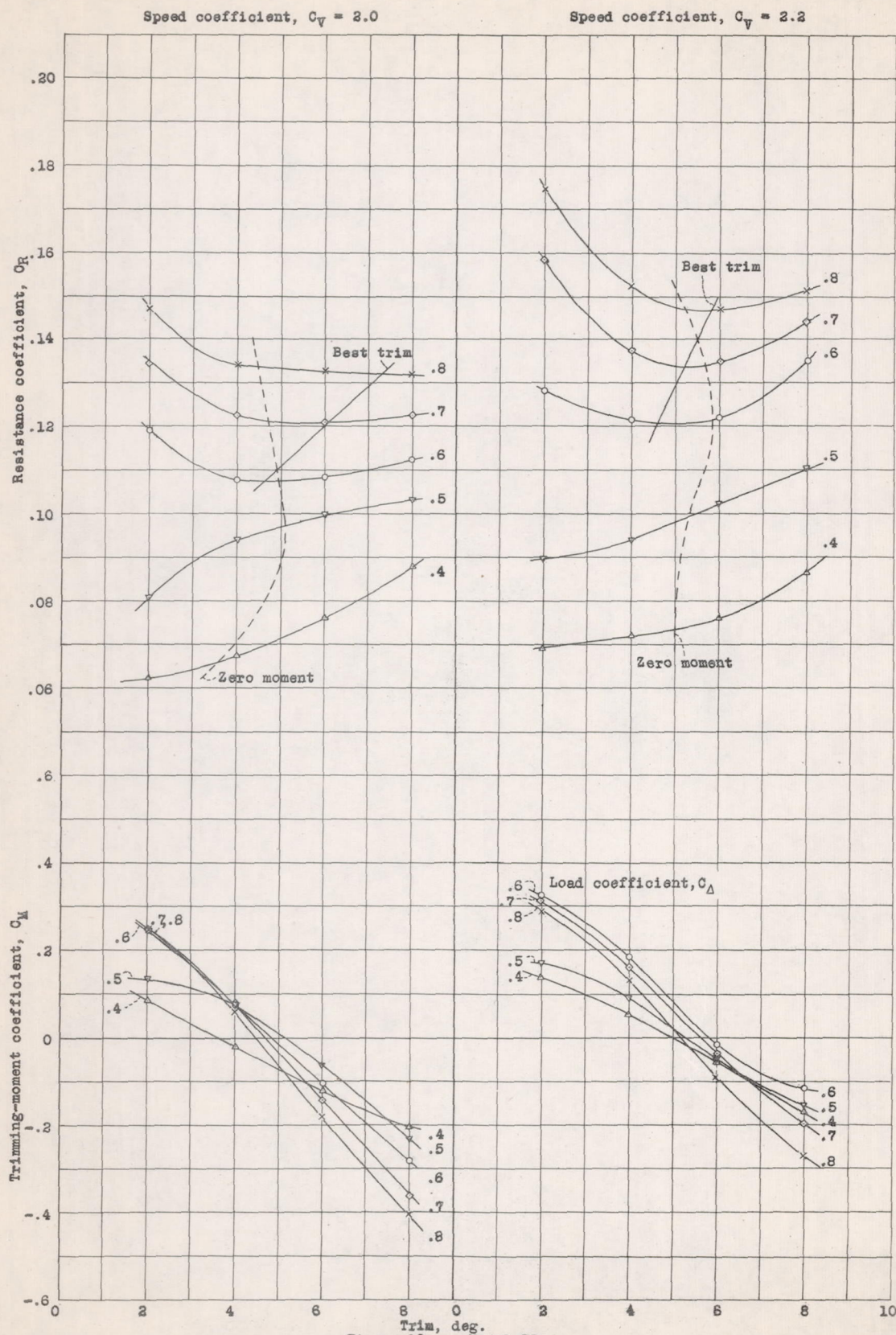


Figure 10c. - Model 75

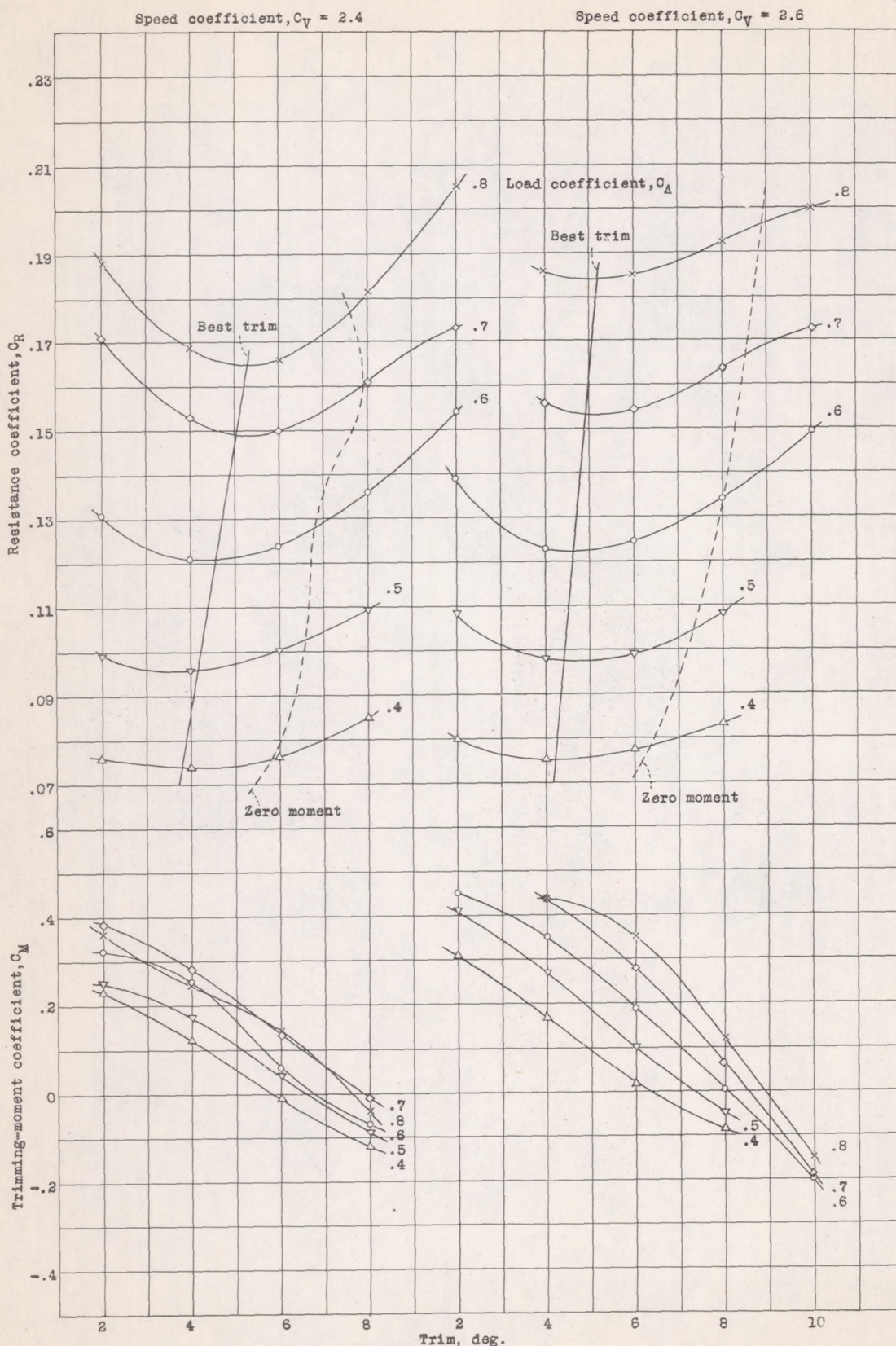
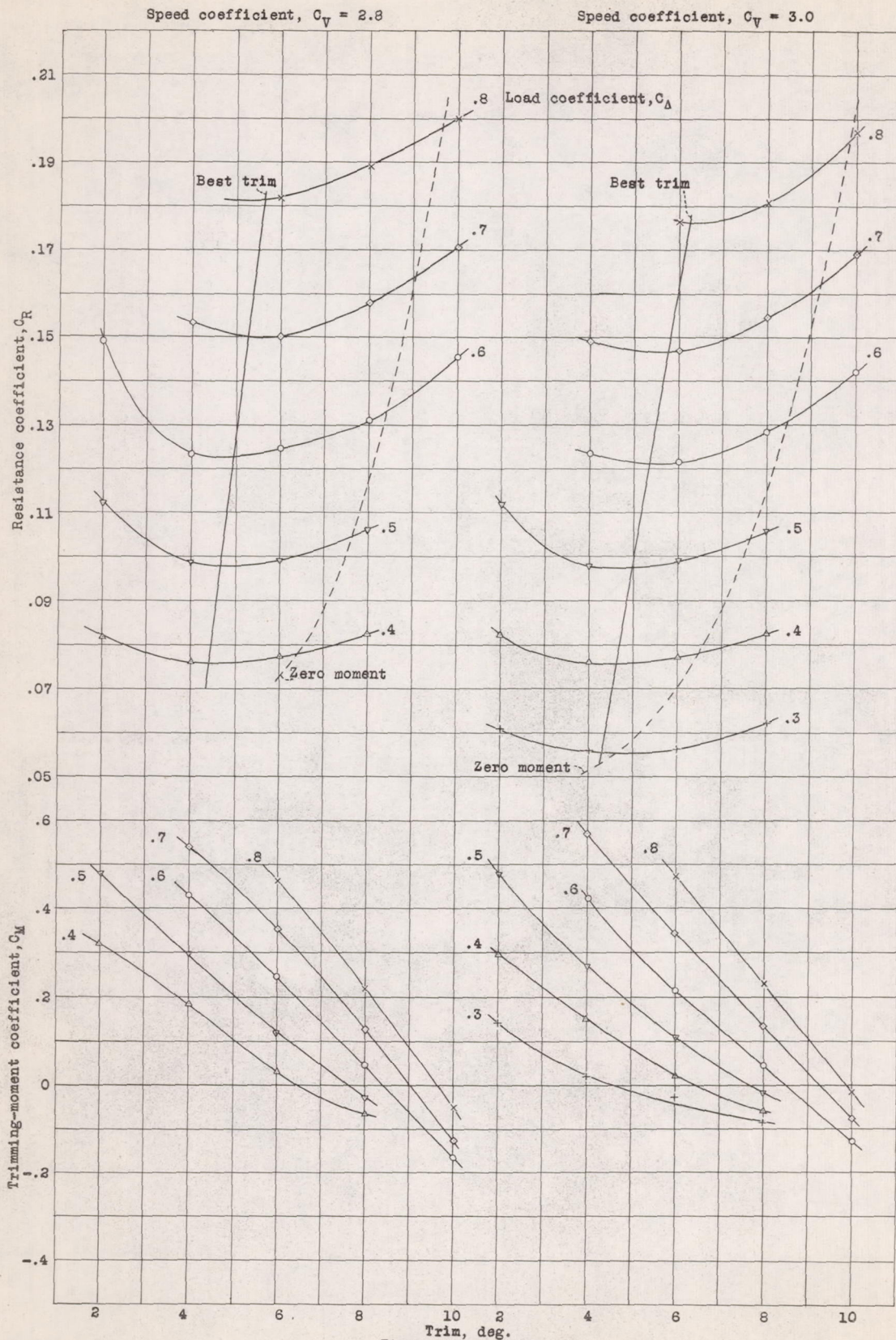


Figure 10d. - Model 75.



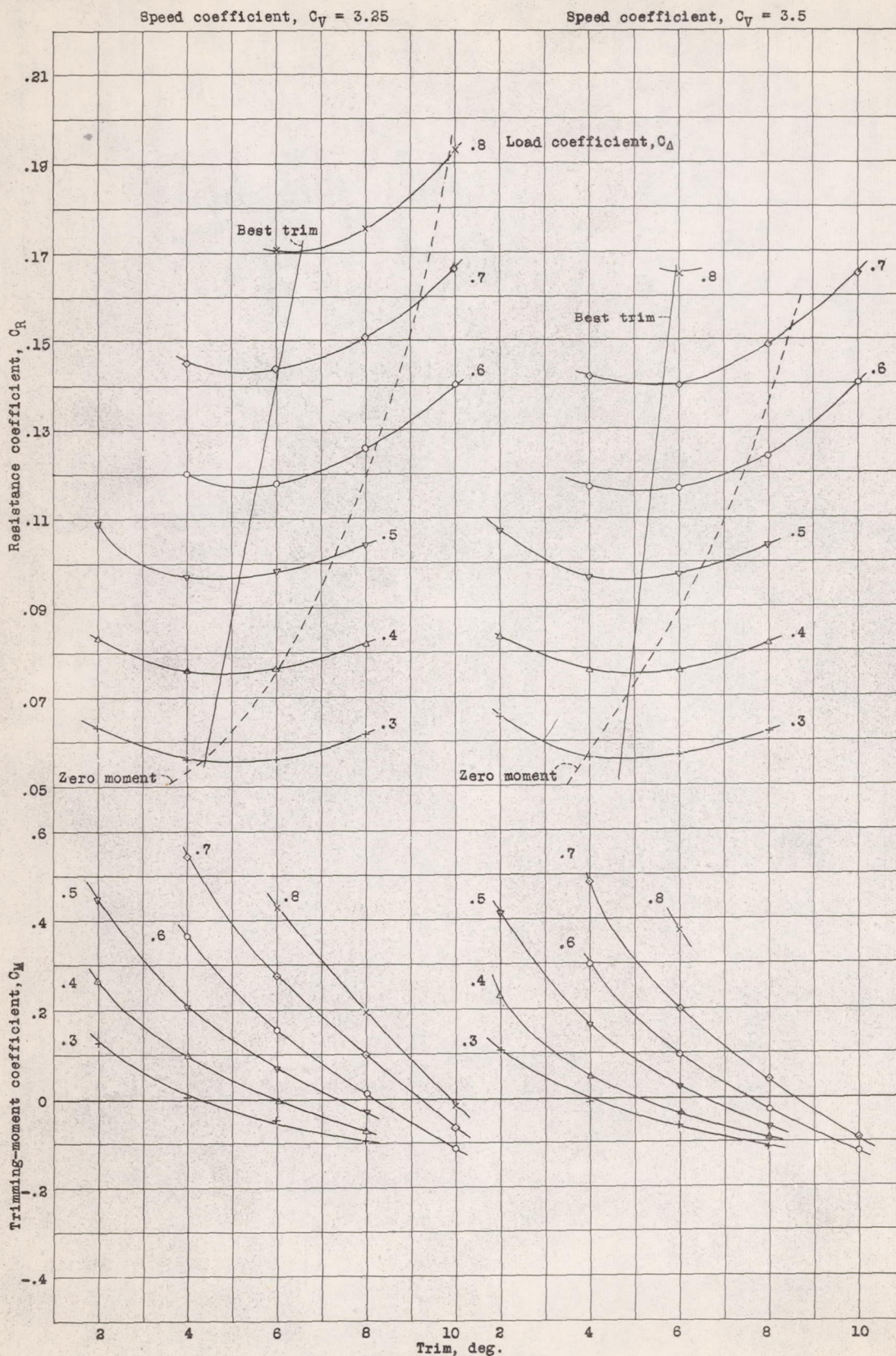
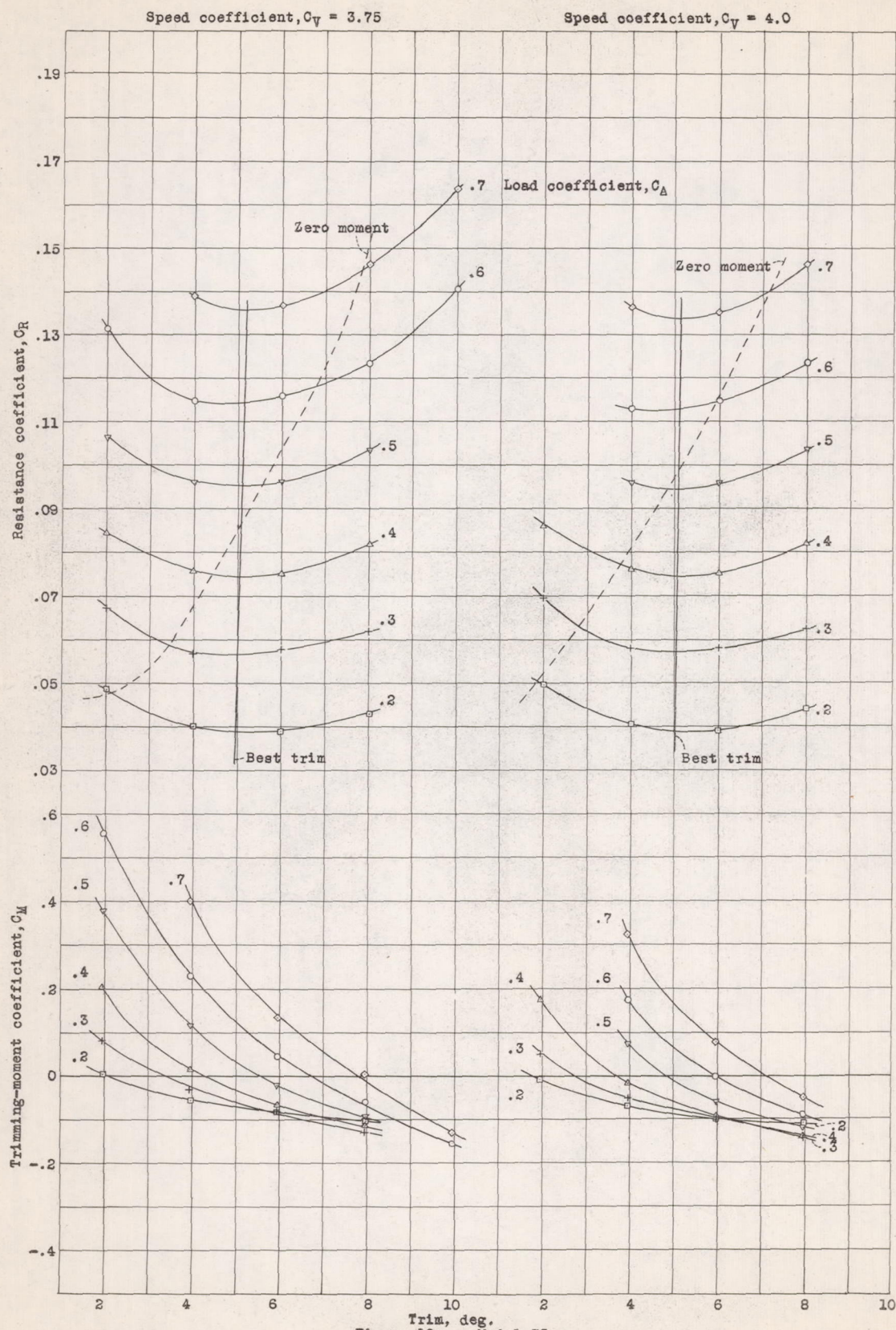
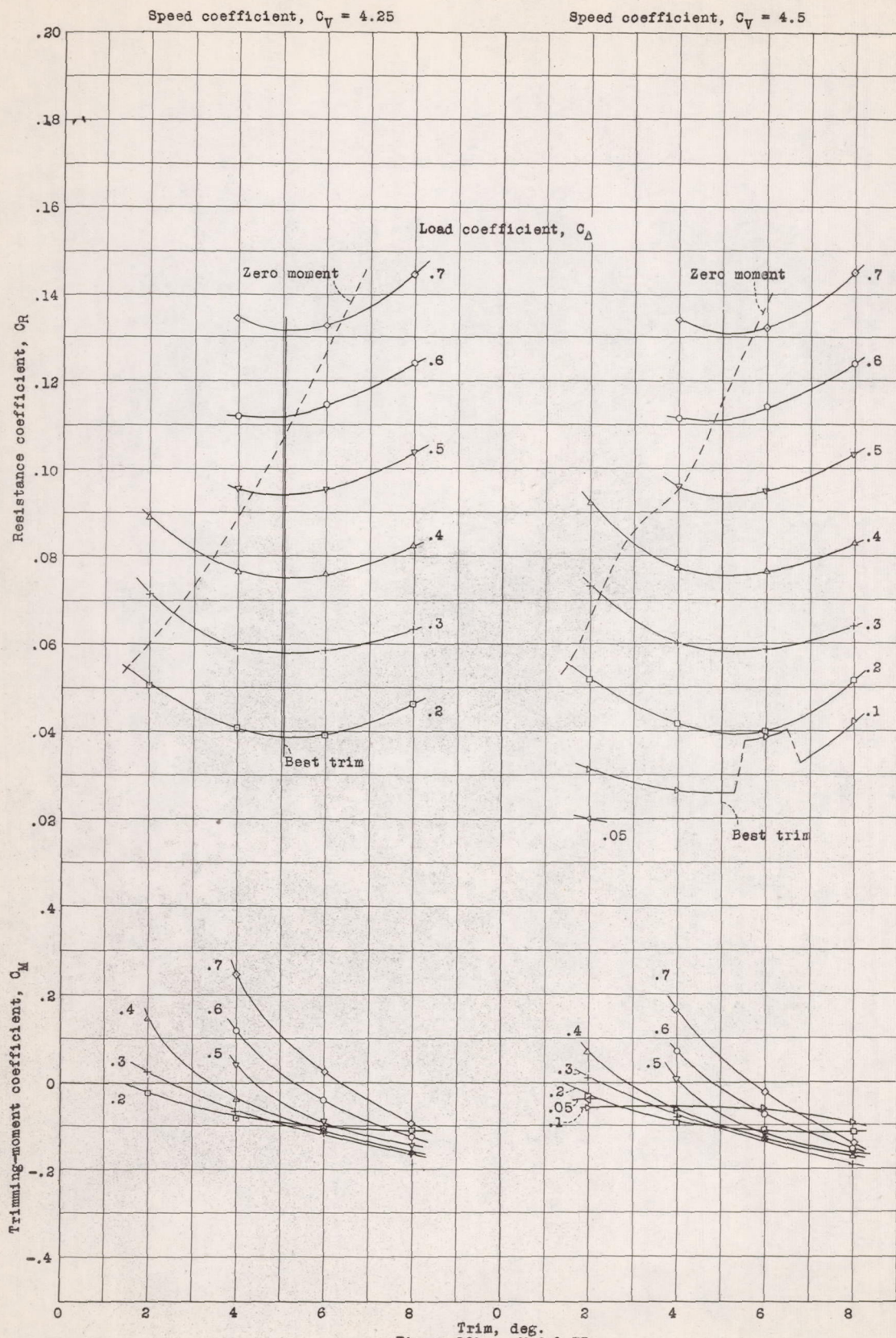


Figure 10f. - Model 75.





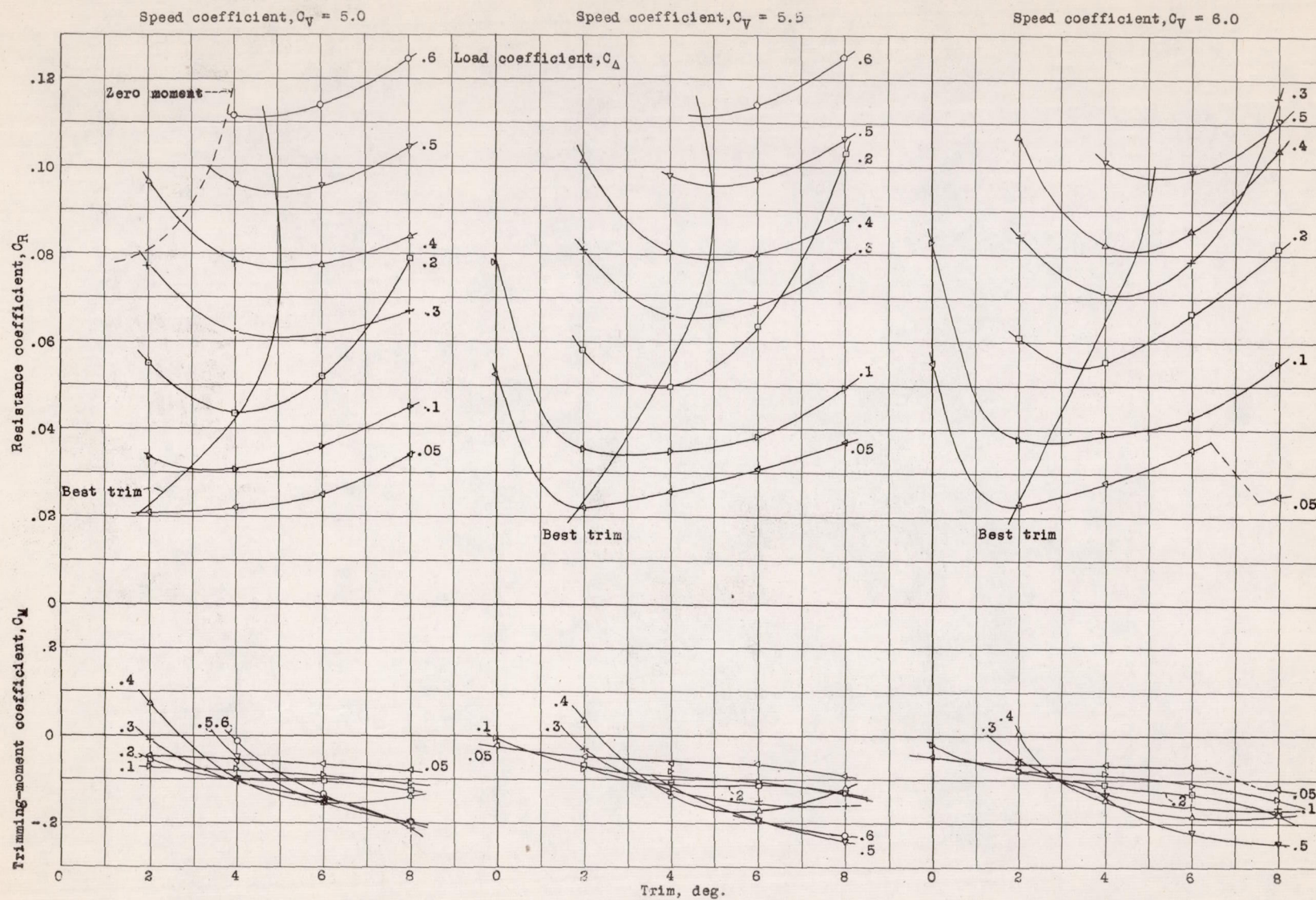


Figure 101. - Model 75.

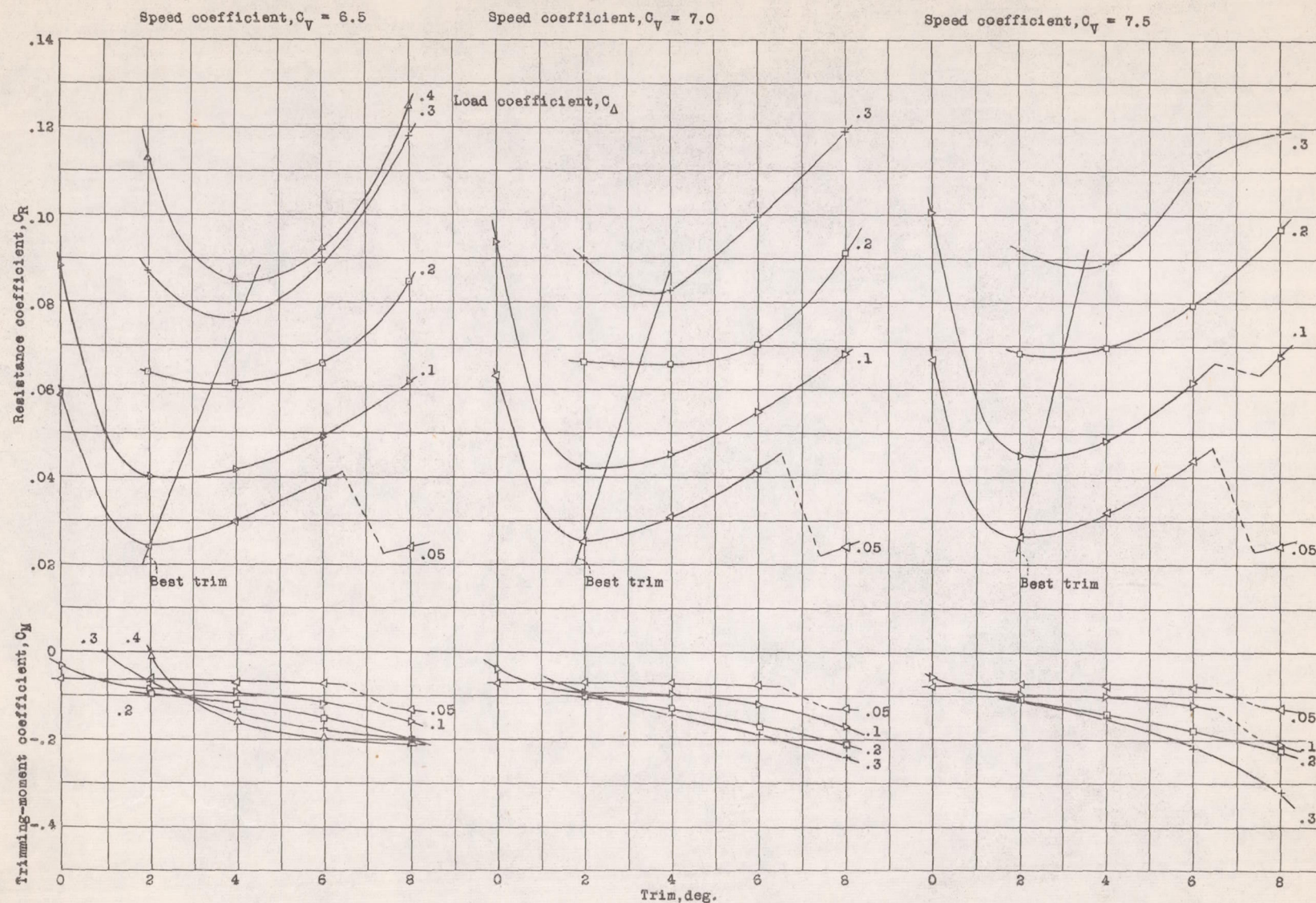
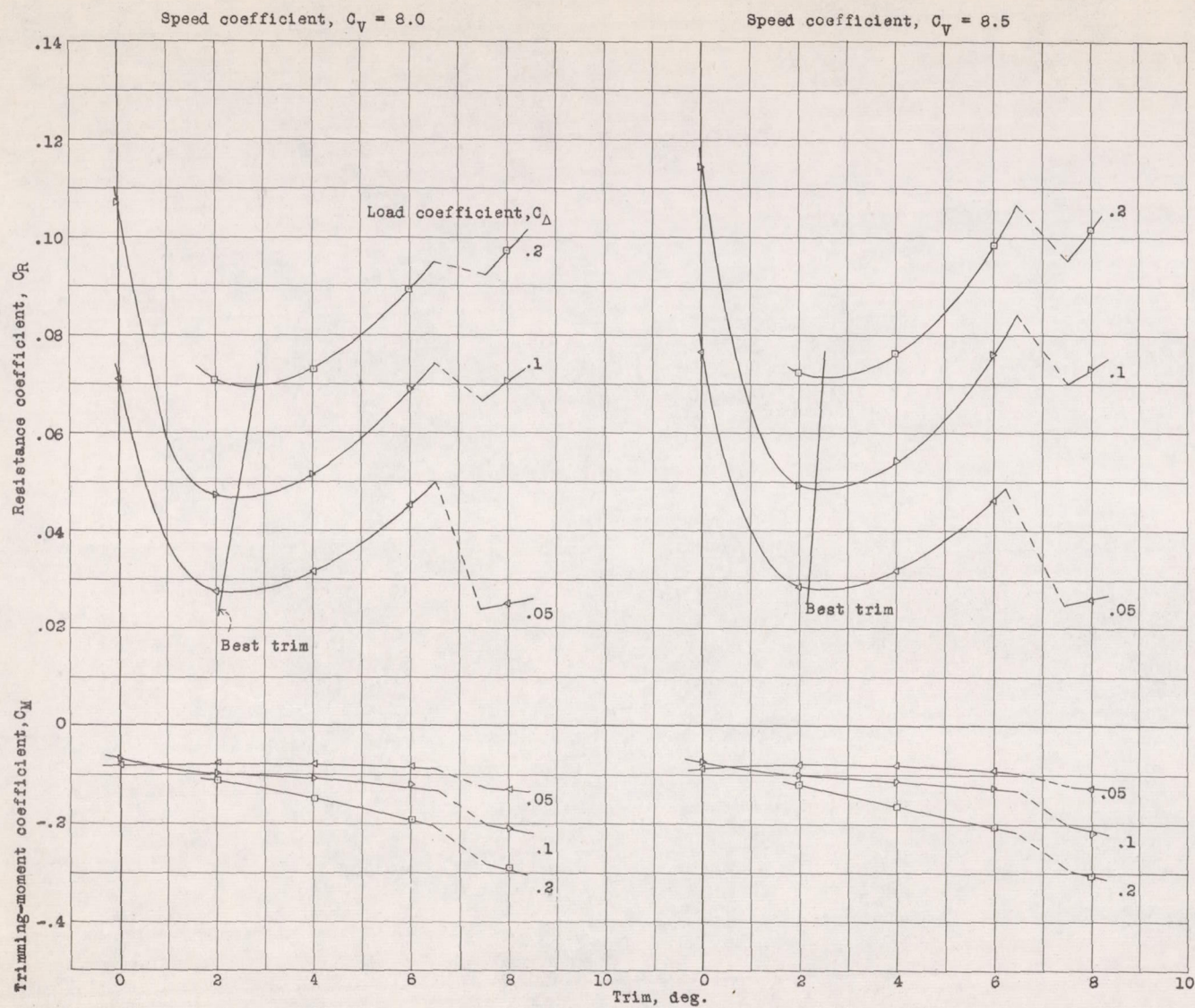


Figure 10j. - Model 75



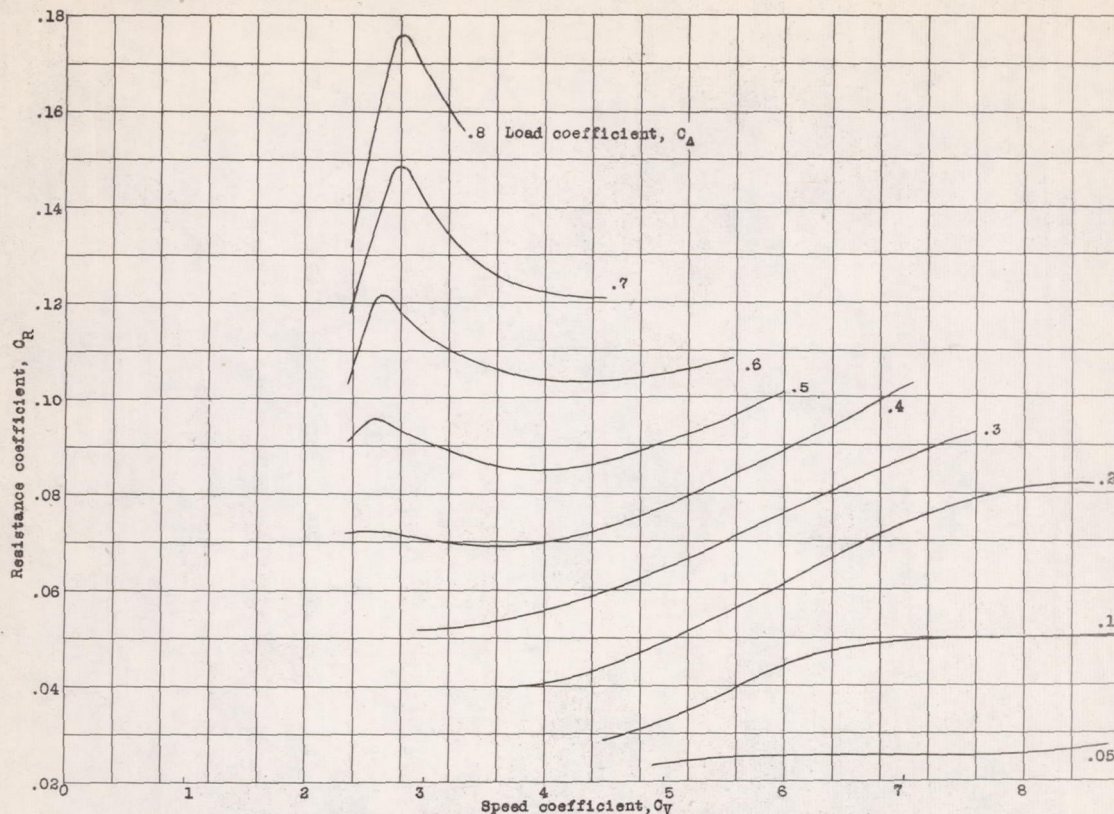


Figure 11. - Model 74-A Resistance coefficient at best trim.

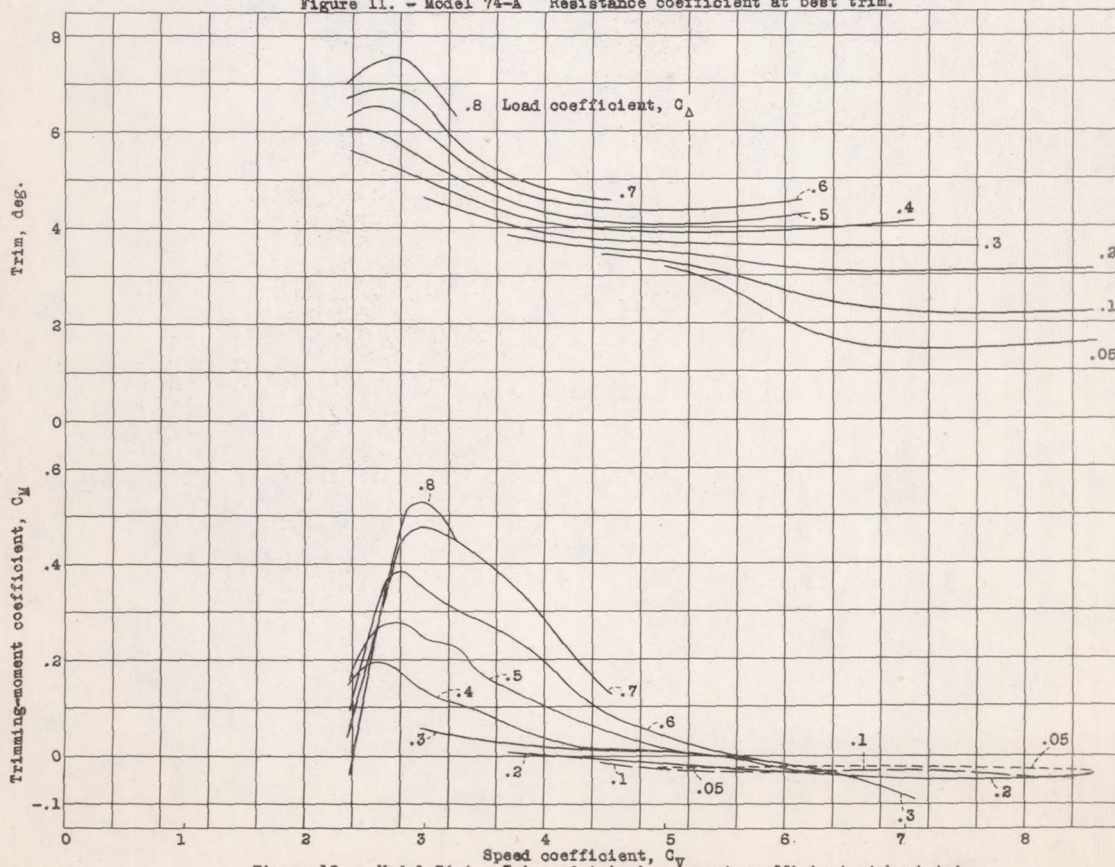


Figure 12. - Model 74-A Trim and trimming-moment coefficient at best trim.

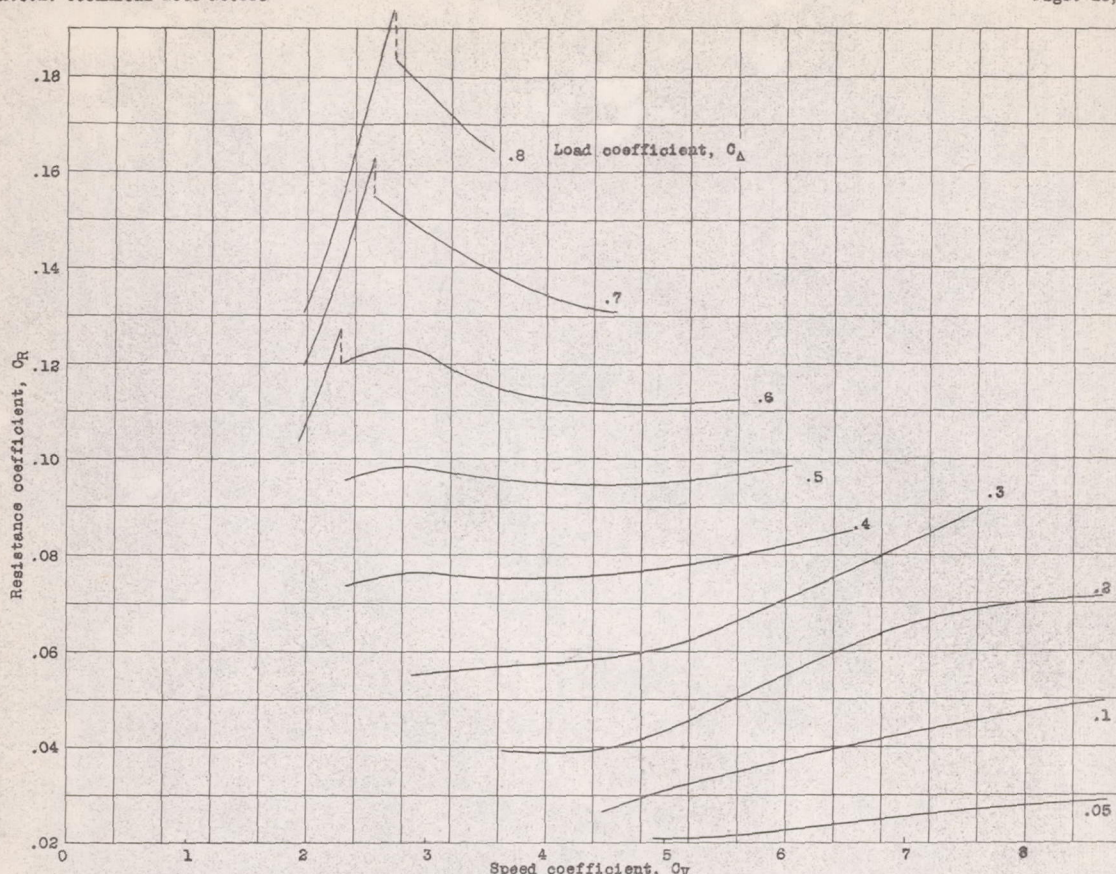


Figure 13. - Model 75. Resistance coefficient at best trim.

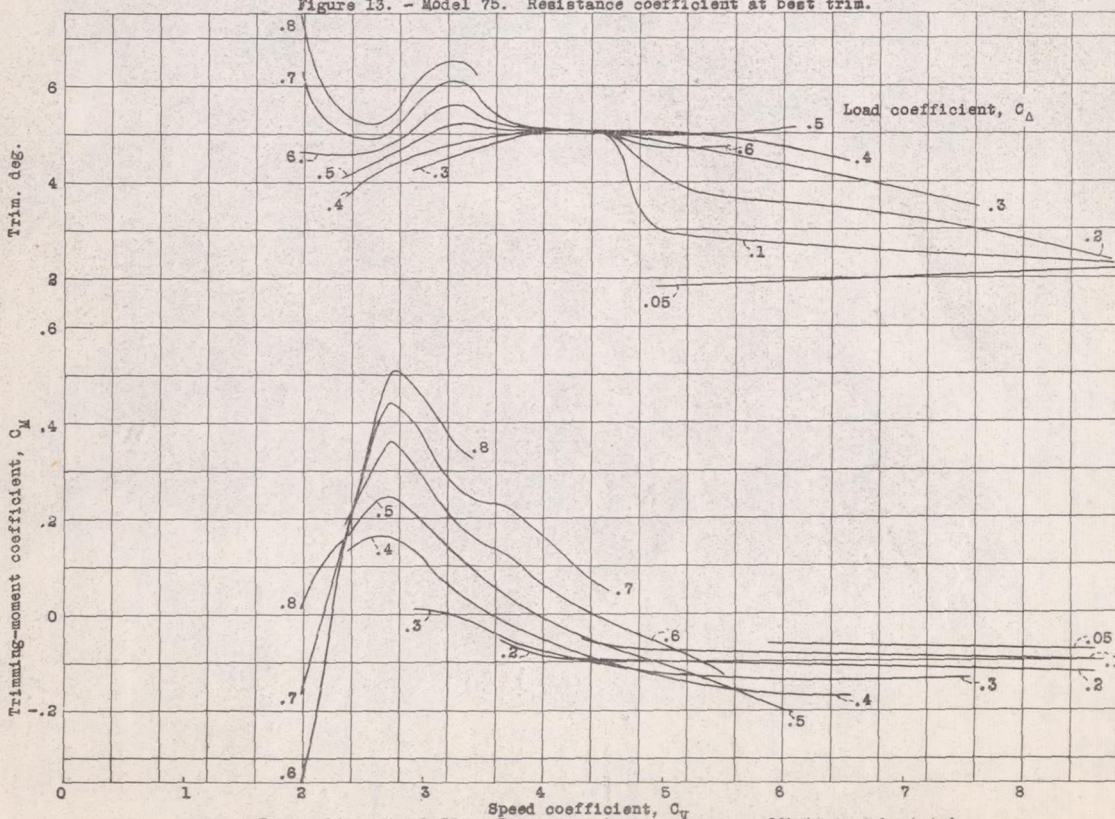
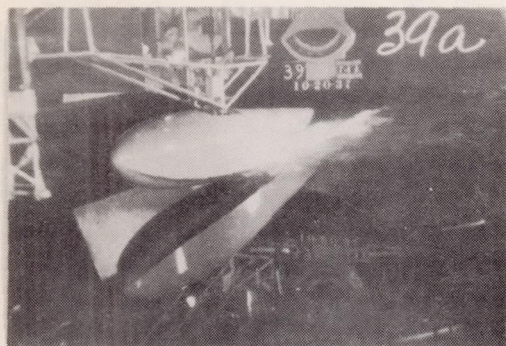


Figure 14. - Model 75. Trim and trimming-moment coefficient at best trim.



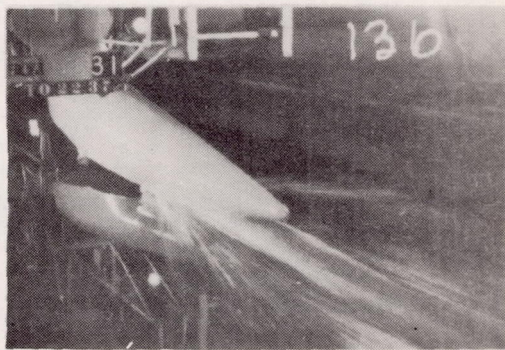
(a) $C_V = 5.29$



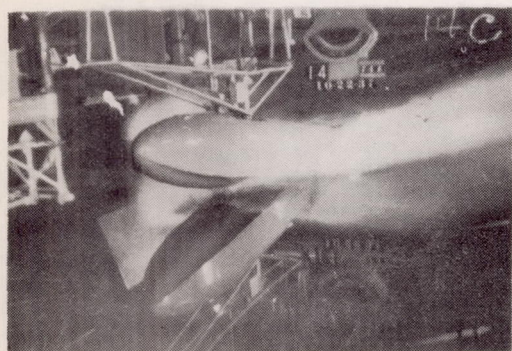
$\tau = 4^\circ$ $C_\Delta = .05$



(b) $C_V = 5.30$



$\tau = 8^\circ$ $C_\Delta = .05$

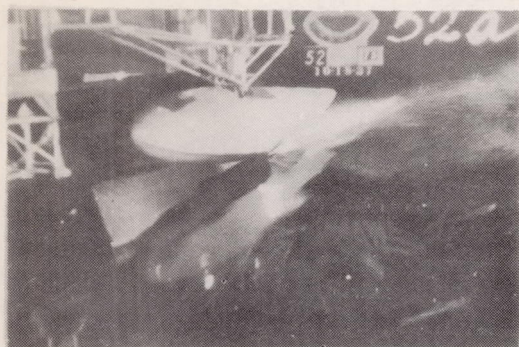


(c) $C_V = 7.55$



$\tau = 8^\circ$ $C_\Delta = .30$

Figure 15. - Spray photographs of model 74-A at fixed trim.



(a) $C_V = 5.38$

$\tau = 4^\circ$

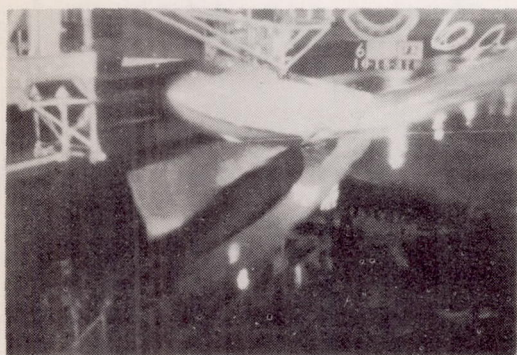
$C_\Delta = .05$



(b) $C_V = 5.20$

$\tau = 8^\circ$

$C_\Delta = .05$



(c) $C_V = 5.24$

$\tau = 6^\circ$

$C_\Delta = .20$



Figure 16. - Spray photographs of model 75 at fixed trim.

Figure 17.- Estimated lift and drag coefficients during take-off for a 125-ton flying boat (drag coefficient of hull excluded).

Split flaps, 0.20 chord, 0.60 span deflected 30 degrees down. 7 degree angle of wing setting to trim base line of hull. Maximum lift coefficient based on take-off Reynolds Number of 22,000,000.

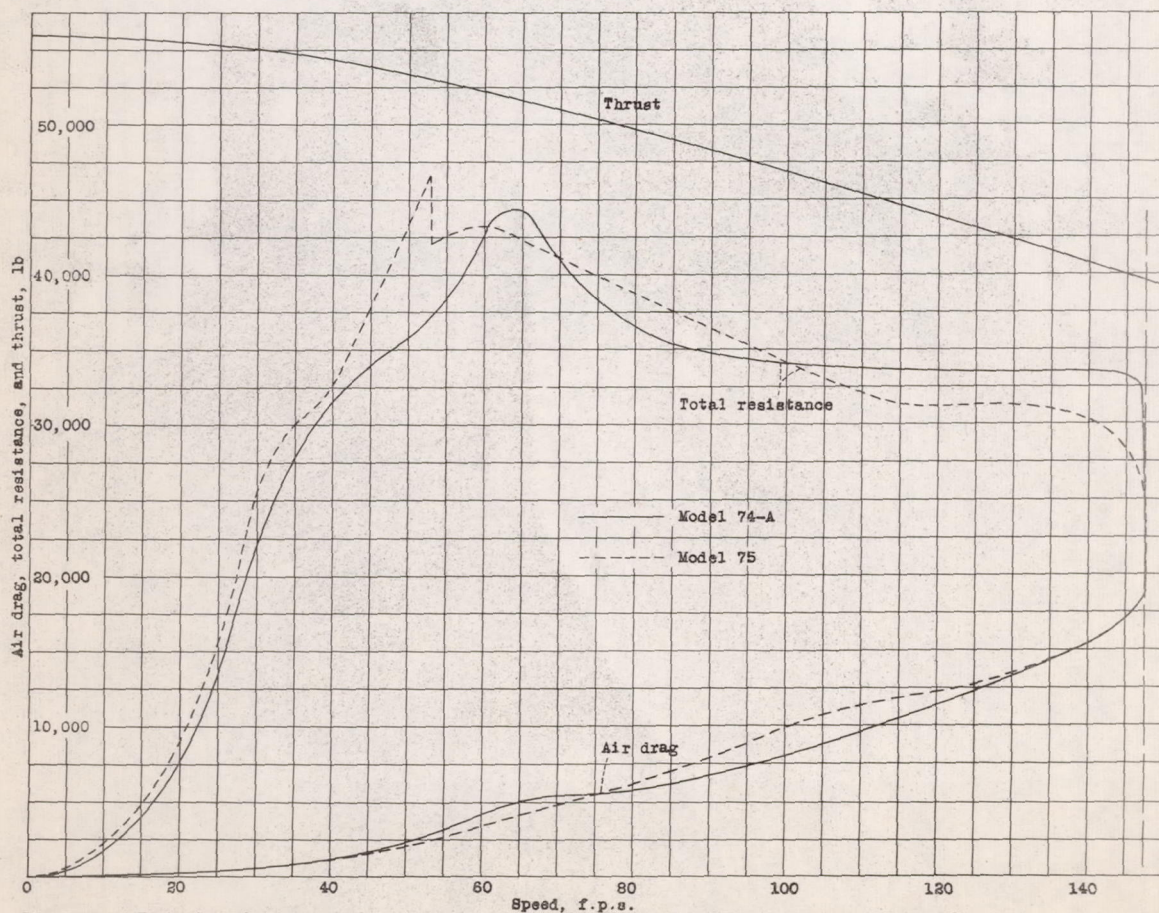
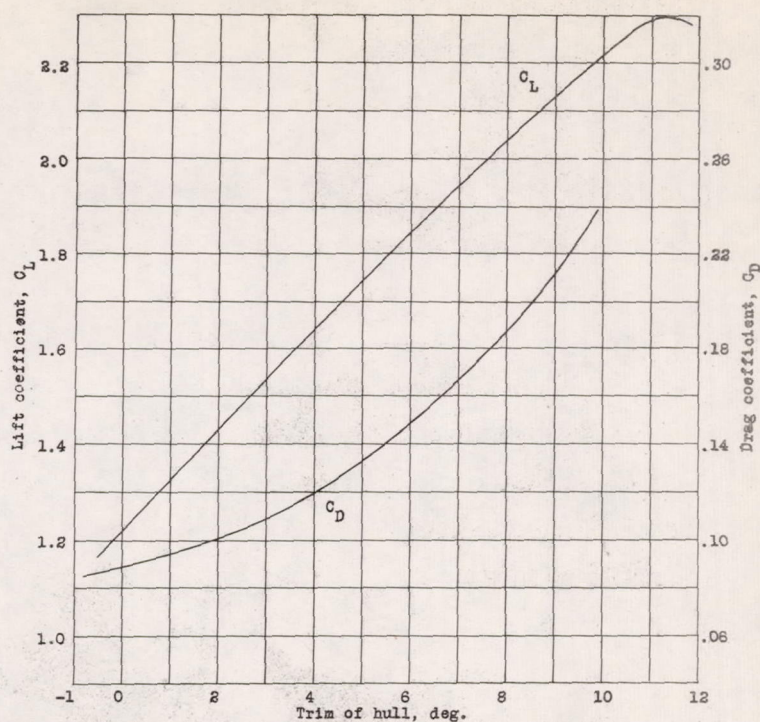


Figure 18.- Estimated air drag, total resistance, and thrust of 125-ton flying boat during take-off.

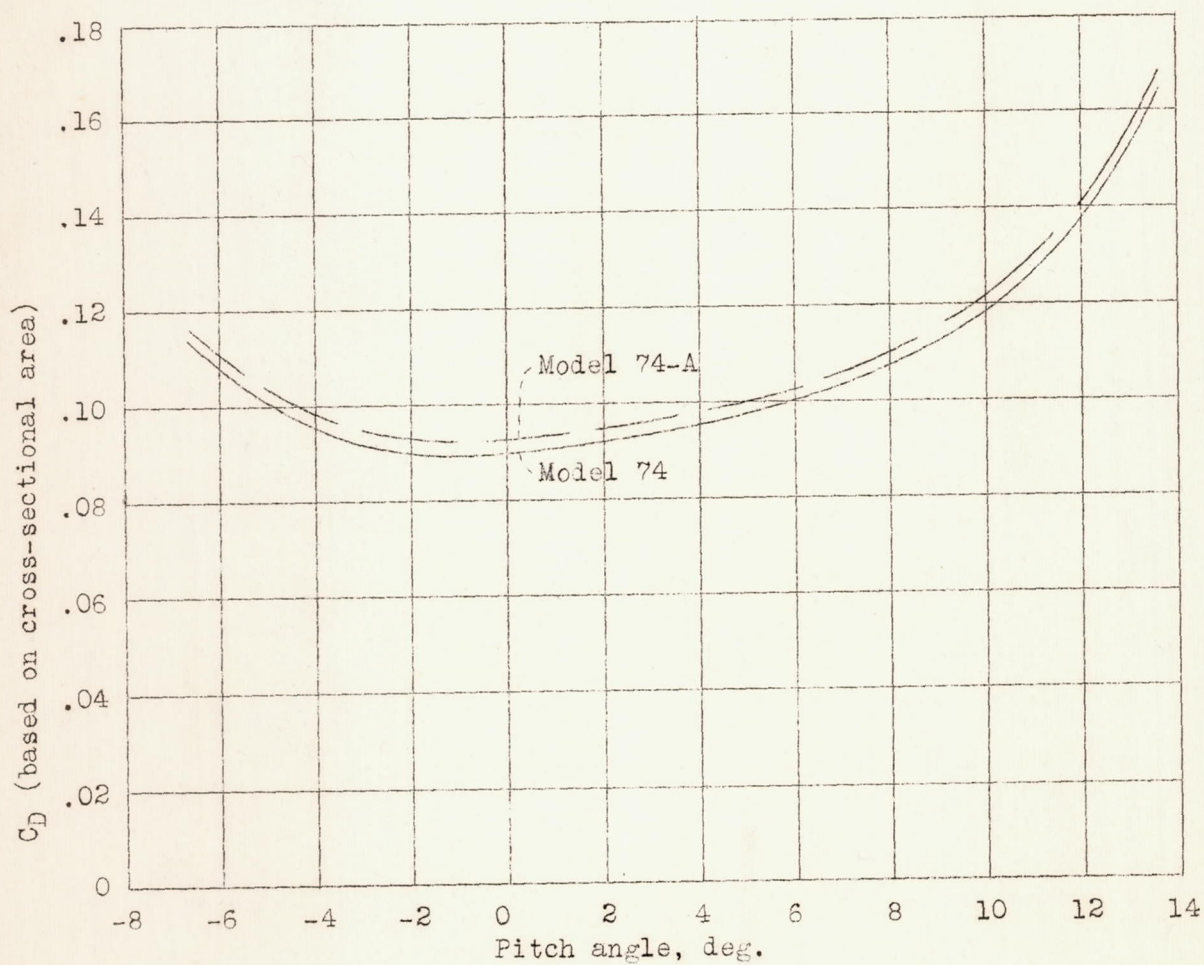


Figure 19.- Drag coefficients for model 74 and estimated change due to modification of model 74 to model 74-A.

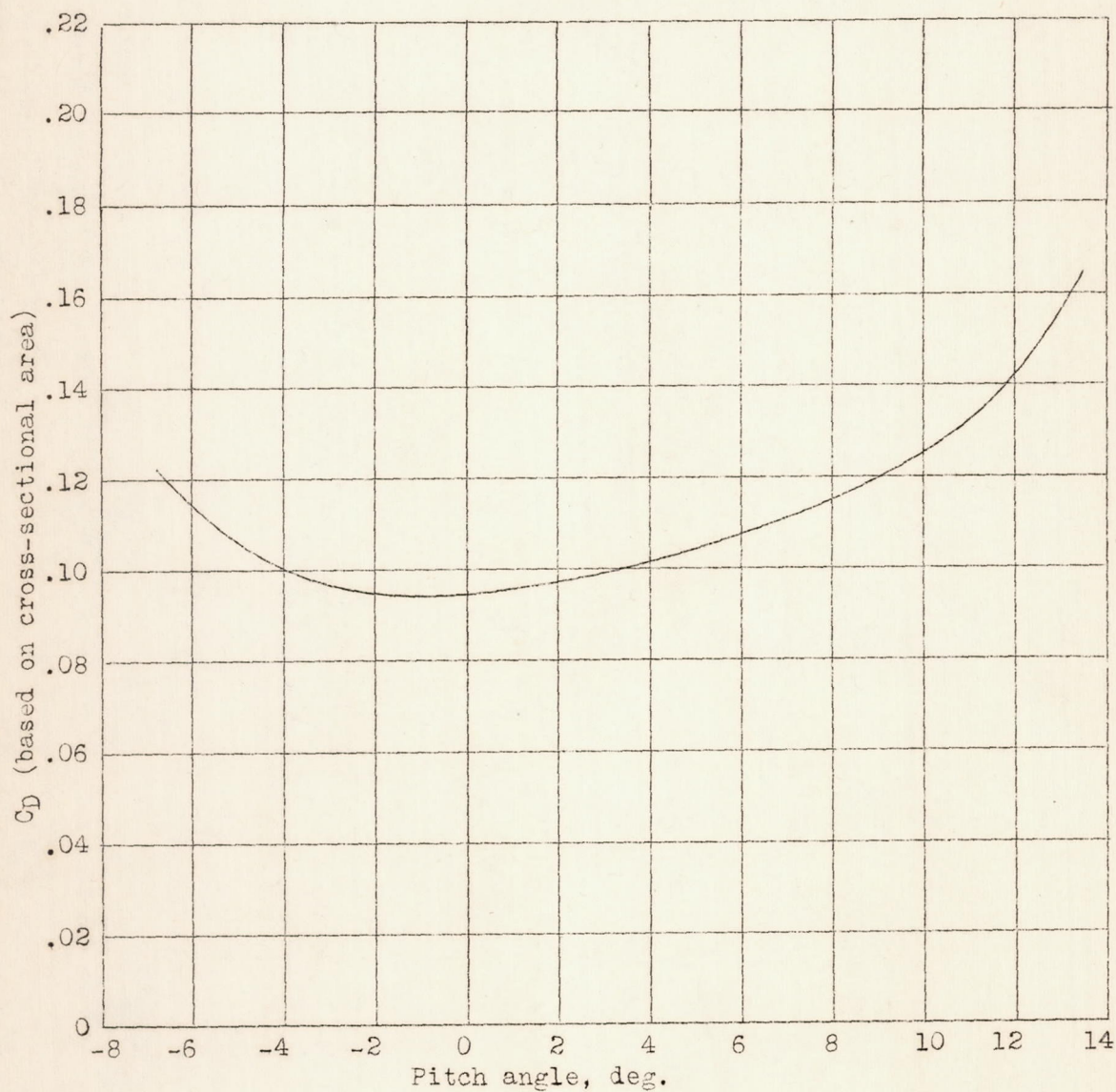


Figure 20.- Drag coefficients for model 75.